Rules for the Application of Sandwich Panel Construction to Ship Structure

July 2019

Lloyd's Register

A guide to the Rules

and published requirements

Rules for the Application of Sandwich Panel Construction to Ship Structure

Introduction

The Rules are published as a complete set.

Rules updating

The Rules are published periodically and changed through a system of Notices between releases.

July 2019

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Section 1
Application

1.1 General

1.1.1 These *Rules for the Application of Sandwich Panel Construction to Ship Structure, July 2019* (hereinafter referred to as the Sandwich Construction Rules) set down the criteria for the assessment of ship structures constructed using steel sandwich panels, *see Ch 1, 2.2 Steel Sandwich Panel definition*, and are applied in addition to other relevant requirements of the *Rules and Regulations for the Classification of Ships* (hereinafter referred to as the Rules for Ships).

1.1.2 The Sandwich Construction Rules are in general applicable to mono hull ships of normal form, proportions and speed constructed in whole or partly using sandwich construction.

1.1.3 Ships of unusual form, proportions, speed, or intended for the carriage of special cargoes, or for special or restricted service, not covered by *Pt 3 Ship Structures (General)* and *Pt 4 Ship Structures (Ship Types)* of the Rules for Ships, will receive individual consideration based on the general standards of the Sandwich Construction Rules (*see also Ch 1, 1.5 Special application*).

1.1.4 It is assumed in the Sandwich Construction Rules that the material of construction for the top and bottom plating of the sandwich panel is steel according to the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials).

1.1.5 Scantlings of structures constructed of aluminium are to be on the basis of equivalent scantlings as set out in *Pt 3, Ch 2, 1.3 Aluminium* of the Rules for Ships. In general, for welded structure, the maximum value for the strength of the material, σ_a , to be used in the scantling derivation is that of the aluminium alloy in the welded condition, where σ_a is defined as the 0,2 per cent butt welded proof stress or 70 per cent of the ultimate strength of the material in the welded condition in N/mm^2, whichever is the lesser.

1.1.6 The Sandwich Construction Rules set down requirements for new construction that in general include a structural design as described in *Ch 1, 3 Structural configuration*.

1.1.7 The Sandwich Construction Rules also include requirements for overlay construction (*see Ch 1, 2.1 General 2.1.5*) applicable to existing ships. Overlay construction is only to be applied when the gauged thickness after diminution is equal to or greater than the rule minimum plate thickness as defined in *Table 3.4.1 Thickness allowance* (*see also Ch 1, 1.5 Special application*).

1.1.8 The core material for the sandwich construction is to be approved by Lloyd's Register (hereinafter referred to as 'LR'), *see Ch 1, 6.3 Core material approval 6.3.1*.

1.2 Loading

1.2.1 The Sandwich Construction Rules are framed on the understanding that ships will be properly loaded and handled; they do not, unless it is stated or implied in the class notation, provide for special distributions or concentrations of loading other than those included in the approved Loading Manual. The Committee may require additional strengthening to be fitted in any ship which, in their opinion, would otherwise be subjected to severe stresses due to particular features of the design, or where it is desired to make provision for exceptional load or ballast conditions.

1.3 Advisory services

1.3.1 The Sandwich Construction Rules do not cover certain technical characteristics, such as stability, trim, vibration, docking arrangements, structural fire protection, etc. The Committee cannot assume responsibility for these matters but is willing to advise upon them on request.

1.4 Corrosion margins

1.4.1 The scantling requirement for plating calculated according to the Rules for Ships includes a corrosion margin.

1.4.2 The requirements for materials of construction, fracture control and corrosion protection, as stipulated in *Pt 3, Ch 2, 1 Materials of construction*, *Pt 3, Ch 2, 2 Fracture control* and *Pt 3, Ch 2, 3 Corrosion protection* respectively of the Rules for Ships, are to be applied.

1.5 Special application

1.5.1 Application of sandwich construction on any of the following areas whether as overlay construction or new construction will require to be specially considered:

(a) Sheer strake, when longitudinal strength is a critical factor.
(b) Upper deck on container ships.
(c) Upper strake of longitudinal bulkheads on container ships.
(d) Fore peak structure including bulbous bow.
(e) Aft peak structure.
(f) Stern frame, pod or rudder trunk integration.
(g) Bilge plating.
(h) Wash bulkheads.
(i) Double bottom floors and girders.
(j) Stem, bar keels, bilge keels, sternframe.
(k) Perforated flats.
(l) Primary structural members.
(m) Corrugated bulkheads.
(n) Deck transverses, girders, stringers.
(o) Decks on oil tankers.
(p) Any structure directly in contact with the oil cargo (e.g. longitudinal bulkhead, transverse bulkhead, inner hull and inner bottom of oil tankers).
(q) Transverse webs in topside tanks of bulk carriers.
(r) Upper decks of LNG carriers.

1.5.2 Where the proposed construction of any part of the hull is of novel design, or where experience, in the opinion of LR, has not sufficiently justified the principle or mode of application involved, special tests or examinations before and during service may be required.

1.6 Interpretation

1.6.1 The interpretation of the Sandwich Construction Rules is the sole responsibility and at the sole discretion of LR. Where there is any doubt regarding the interpretation of the Sandwich Construction Rules it is the builder's and/or designer's responsibility to obtain clarification from LR prior to submission of plans and data for design appraisal.

1.6.2 Where applicable, the Sandwich Construction Rules take into account unified requirements established by the International Association of Classification Societies.

1.7 Equivalents

1.7.1 Where calculation procedures other than those available within the ‘ShipRight Procedures’ are employed, supporting documentation is to be submitted for appraisal and this is to include details of the following:

(a) calculation methods, assumptions and references;
(b) loading;
(c) structural modelling;
(d) design criteria and their derivation, e.g. permissible stresses, factors of safety against plate panel instability, etc.

1.7.2 LR will be willing to consider the use of Builders’ programs for direct calculations in the following cases:

(a) Where it can be established that the program has previously been satisfactorily used to perform a direct calculation similar to that now submitted.

(b) Where sufficient information and evidence of satisfactory performance is submitted to substantiate the validity of the computation performed by the program.

1.7.3 Alternative scantlings and arrangements may be accepted as equivalent to the Rule requirements. Details of such proposals are to be submitted for consideration and this is to include the following:

(a) calculation methods;

(b) assumptions and references;

(c) loading;

(d) structural modelling;

(e) stress and deflection output.

1.7.4 All direct calculations are to be submitted for examination.

Section 2
Definitions and structural terms

2.1 General

2.1.1 For the purpose of clarifying the nomenclature of items of structure referred to throughout the Sandwich Construction Rules, unless expressly stated otherwise, the terms used herein have the meanings defined in the following definitions, *see also Pt 3, Ch 3, 1.1 Application 1.1.1* of the Rules for Ships.

2.1.2 **Primary members** are those members supporting the steel sandwich panel and will be typically:

(a) Deck structure – deck transverses and girders.

(b) Side structure – side transverses and side stringers.

(c) Bulkheads – vertical webs and bulkhead stringers.

(d) Single and double bottom structure – floors and girders.

2.1.3 The **fore end** region is considered to include all structure forward of 0,7*L*.

2.1.4 The **aft end** region is considered to include all structure aft of 0,3*L*.

2.1.5 **Overlay** or **Overlay construction** is defined as when the existing steel structure is overlaid with elastomer and a new steel top plate according to the requirements of *Ch 2 Material Manufacture and Construction Procedures* and *Ch 3 Design Basis for Panels*.

2.1.6 **Design organisation** is the organisation that provides the design and construction plans.

2.1.7 The **Design documentation** refers to the 'Construction Procedure Report' or 'Overlay Procedure Report' as applicable.

2.2 Steel Sandwich Panel definition

2.2.1 A **Steel Sandwich Panel** consists of three layers. Two external layers of steel and an internal core layer, *see Figure 1.2.1 Steel sandwich panel scantling definition*.

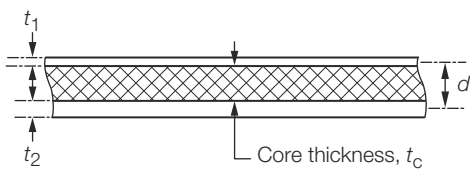


Figure 1.2.1 Steel sandwich panel scantling definition

2.2.2 The term **core** applies to the layer between the steel plates. The *core* is injected in between the *top* and *bottom* steel plates and bonds mechanically directly to the steel surfaces.

2.2.3 The term **bottom plate** applies to the steel plating to which primary members are attached.

2.2.4 The term **top plate** applies to the steel plating exposed to sea, weather or cargo.

2.2.5 **Cavity** is defined as the space enclosed by the top and bottom steel plates and perimeter bars.

2.2.6 **Panel** is defined as the sandwich panel enclosed by the primary members.

2.2.7 The term **spacer** applies to the square or round block made of elastomer or steel secured to the bottom plate. A spacer is intended to maintain the required distance between the top and bottom plates, *see Ch 2, 3.3 Preparation of steel 3.3.5*.

Section 3
Structural configuration

3.1 General

3.1.1 Requirements are given in the Sandwich Construction Rules for ships constructed either fully or partly of sandwich panels.

3.1.2 This Section describes a basic structural configuration as set out in *Ch 1, 3.2 New construction* for new construction and *Ch 1, 3.3 Overlay construction* for overlay construction.

3.1.3 Primary members support the sandwich panels.

3.1.4 These provisions do not preclude the fitting of additional girders, transverses or floors in order to maintain adequate aspect ratio, *see Ch 4, 2.1 General*.

3.1.5 Temperature control pressure relief plugs are in general fitted to the steel sandwich panels. The size, number and location are to be such that they do not compromise the structural capability of the sandwich construction.

3.2 New construction

3.2.1 This Section describes a basic structural configuration for new construction as shown in *Figure 1.3.1 Diagrammatic arrangement of a typical sandwich new construction (for illustration only and not to scale)*.

3.2.2 The main components of a structural configuration employing sandwich construction are:

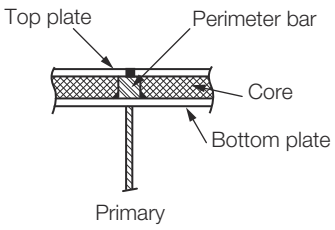
(a) Top plate.
(b) Bottom plate.
(c) Elastomer core.
(d) Primary member, supporting the panel.
(e) Perimeter bar, welded to the bottom plate to define the perimeter edges of the injection cavities directly above supporting members (primary members, floors, girders, bulkheads).
(f) Temperature control pressure relief plugs, where fitted, *see also Ch 1, 3.1 General 3.1.5*.

3.3 Overlay construction

3.3.1 This Section describes a basic structural configuration for overlay construction as shown in *Figure 1.3.2 Diagrammatic arrangement of a typical sandwich overlay construction (for illustration only and not to scale)*.

3.3.2 The main components of a structural configuration employing overlay construction are:

(a) New steel top plate (becomes the new wearing surface).
(b) Elastomer core.
(c) Existing steel plate including any primary and secondary stiffeners attached to it.
(d) Perimeter bars (flat bars). Attached to the existing plating directly above transverse and longitudinal supporting structure. Size and number of perimeter bars dependent on the cavity size and not necessarily located above every supporting structure.
(e) Temperature control pressure relief plugs, where fitted, *see also Ch 1, 3.1 General 3.1.5*.



Typical primary member, perimeter bar arrangement

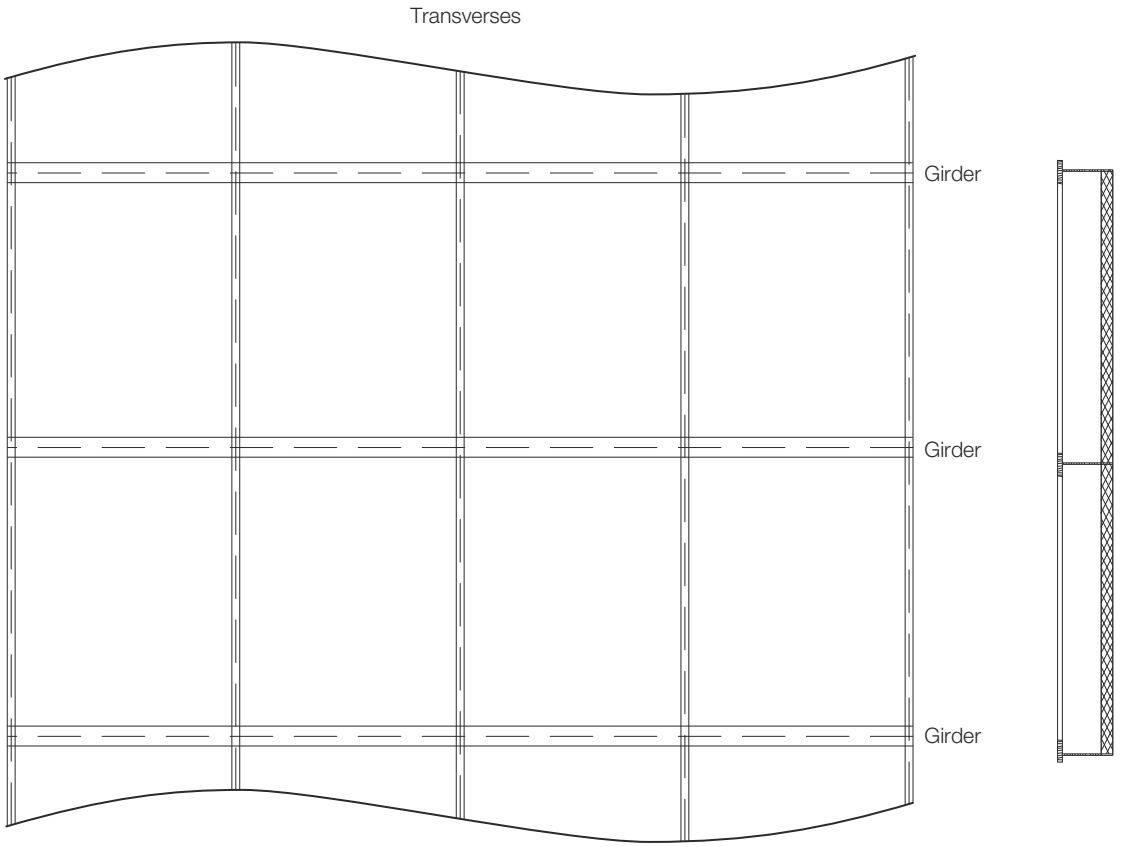


Figure 1.3.1 Diagrammatic arrangement of a typical sandwich new construction (for illustration only and not to scale)

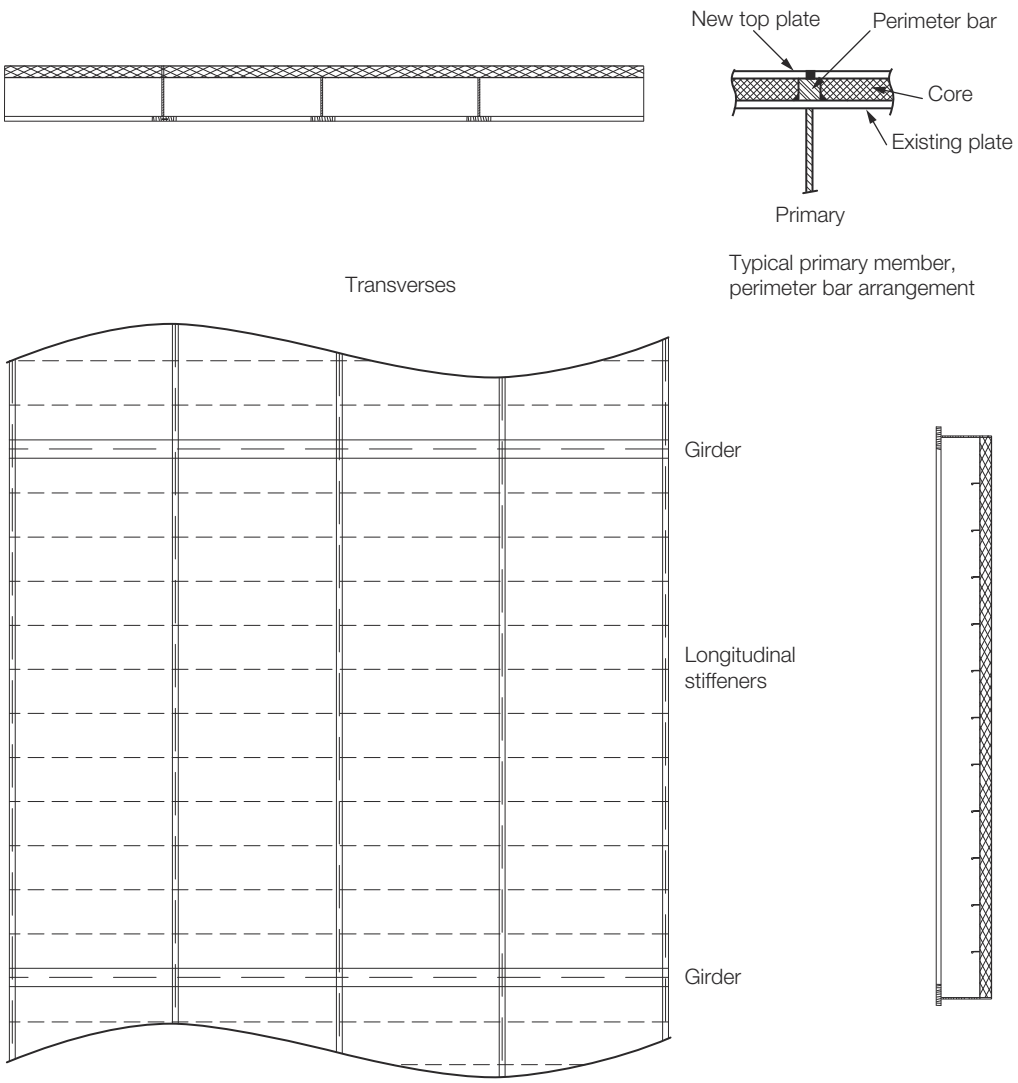


Figure 1.3.2 Diagrammatic arrangement of a typical sandwich overlay construction (for illustration only and not to scale)

Section 4
Rule structural concept

4.1 General

4.1.1 The Sandwich Construction Rules are formulated to provide for scantling derivation for designs where the sandwich panel forms the flange of the primary members, *see Pt 3, Ch 3, 3.2 Geometric properties of section* of the Rules for Ships. Details of the requirements are given in *Ch 3 Design Basis for Panels* and *Ch 4 Design Basis and Scantling Determination of Primary Structure*.

4.1.2 Scantling requirements in respect of miscellaneous items of structure such as local foundations, base plates, insert plates, bollards, etc. are not specifically indicated within the Sandwich Construction Rules. However the acceptance of such items will be specially considered on the basis of experience, good practice and direct calculation where appropriate.

4.2 Scantlings

4.2.1 The scantling derivation of a steel sandwich panel is based on an equivalent strength approach whereby the strength of the steel sandwich panel is to be equivalent to a conventionally framed steel panel construction, *see Ch 3 Design Basis for Panels* and *Ch 4 Design Basis and Scantling Determination of Primary Structure* for the thickness requirements.

4.2.2 Where steel sandwich panel construction is to be used as part of the continuous longitudinal material contributing to longitudinal strength, the structure is also to be in accordance with *Pt 3, Ch 4 Longitudinal Strength* of the Rules for Ships.

Section 5
Class notations

5.1 Class notations

5.1.1 Sea-going ships complying with these requirements, together with relevant requirements as stipulated in the Rules for Ships will be eligible to be classed as, e.g.

(a) **+100A1 Bulk Carrier, Sandwich Construction (pt)**

5.1.2 The notation **Sandwich Construction (pt)** serves to identify that the ship as has been built partly using sandwich construction. The exact location and extent are to be included on all construction plans.

5.1.3 The 'ShipRight Procedures' for the hull construction of ships are detailed in *Pt 3, Ch 16 ShipRight Procedures for the Design, Construction and Lifetime Care of Ships* of the Rules for Ships and the classification notations and descriptive notes associated with these procedures are given in *Pt 1, Ch 2, 2 Character of classification and class notations* of the Rules for Ships.

5.1.4 Additional applicable class notations may be assigned at the request of the Owner and at the discretion of the Committee.

5.1.5 Reference is made to *Pt 1, Ch 2 Classification Regulations* of the Rules for Ships with respect to the Regulations for classification and assignment of class notations.

Section 6
Information required

6.1 Plans to be submitted

6.1.1 Plans are to be of sufficient detail for plan appraisal purposes. The submitted plans are to show all plating thickness, stiffener sizes and spacings, bracket arrangements and connections. Where appropriate, the plans should clearly show the allowance for corrosion margin or Owner's extra. Welding, constructional arrangements and tolerances are also to be submitted and this may be in the form of a booklet.

6.1.2 In addition to plans as normally required by the relevant parts and chapters of the Rules for Ships applicable to the ship type, the plans and information stated in *Ch 1, 6.1 Plans to be submitted 6.1.3* to *Ch 1, 6.1 Plans to be submitted 6.1.6* are also required to be submitted as applicable.

6.1.3 Plans covering the following items are to be submitted:

(a) Drawings with the sandwich panel specifications (thickness of top, bottom plating and core thickness).
(b) When Sandwich construction has been utilised partly, the exact extent and location are to be indicated on all relevant plans.
(c) Cavity layouts and details.
(d) Details of integration with conventional steel construction, if applicable.
(e) Details of integration with primary members, bulkheads, etc. For typical design details, *see Ch 2, 5 Typical design details*.
(f) Construction procedure report.
(g) The arrangement of equipments, supports, foundations, etc. in conjunction with their weight and working load information.

6.1.4 For overlay construction the following information, in addition to the information required in *Ch 1, 6.1 Plans to be submitted 6.1.3* as applicable, is also to be submitted:

(a) Thickness gaugings of the existing structure to be overlaid.
(b) Overlay scantlings – core and new steel plate thicknesses.
(c) Cavity layouts and details.
(d) Details of integration with the existing structure.
(e) Plans of any proposed modifications and changes to the previously approved plans (of the existing structure) are to be submitted for approval prior to the commencement of any work.
(f) A detailed overlay procedure report.

6.1.5 To enable the appraisal of the proposed arrangement, the following supporting documents are also to be submitted:

(a) Temperature control pressure relief plugs, where fitted – size, number and location.

6.1.6 The design documentation is to be submitted to LR to enable the approval of the steel sandwich panels of the ship and is to contain the following information:

(a) detailed description of the preparation of steel;
(b) for overlay construction a description of the preparation of the existing steel plate;
(c) description of surface roughness to be achieved;
(d) description of the arrangement of spacers and perimeter bars;
(e) description of the panel restraint and arrangement;
(f) description of how the material components are checked prior to injection and elastomer preparation;
(g) machinery set-up and calibration procedure;
(h) description of the cavity preparation and injection process;
(i) a description of how the effects of weld heat input will be avoided;
(j) description of the cavity humidity detection process and method;
(k) max void size;
(l) a description of the repair process.

6.2 Submission of direct calculation

6.2.1 Direct calculations may be specifically required by the Sandwich Construction Rules or may be required for ships having novel design features or may be submitted in support of alternative arrangements and scantlings.

6.2.2 In cases where direct calculations have been carried out using ShipRight procedures, the information required therein is to be submitted.

6.2.3 In general, when direct calculations have been carried out the following information is to be submitted as applicable:

(a) A description of the structural modelling.
(b) A summary of analysis parameters including properties and boundary conditions.
(c) Details of the loading conditions and the means of applying loads.
(d) A comprehensive summary of calculation results. Sample calculations should be submitted where appropriate.

6.2.4 In general, submission of large volumes of input and output data associated with such programs as finite element analysis will not be necessary.

6.2.5 The responsibility for error free specification and input of program data and the subsequent correct transposition of output rests with the Design Organisation.

6.2.6 It is recommended that the designer discuss the analysis requirements with LR as early as possible in the design cycle.

6.3 Core material approval

6.3.1 Additional information is required as detailed in *Ch 2, 2 Core material* for approval of the core material.

Section 7
Symbols

7.1 General

7.1.1 All principal particulars not explicitly defined here are to be as defined in the Rules for Ships.

7.2 Symbols

7.2.1 The following symbols are applicable to the Sandwich Construction Rules unless otherwise stated:

(a)

a = length of the panel at longest edge, in mm

b = breadth of the panel at shortest edge, in mm

d = $0,5(t_1 + t_2) + t_c$, in mm

D = flexural rigidity of the sandwich, in Nmm

= $= \frac{E_f t_1 t_2 d^2}{(t_1 + t_2)}$

E_f = modulus of elasticity of the top and bottom plates, in N/mm^2

= $2,06 \times 10^5$ for steel

G_c = minimum design shear modulus of core material, in N/mm^2, as shown on approval certificate

t_1 = thickness of the top plate, in mm

t_2 = thickness of the bottom plate, in mm

t_{a1} = thickness allowance for the top plate, in mm

t_{a2} = thickness allowance for the bottom plate, in mm

t_c = thickness of the core, in mm

ν = Poisson's ratio

= 0,3

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CHAPTER 4 DESIGN BASIS AND SCANTLING DETERMINATION OF PRIMARY STRUCTURE

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Section 1
General requirements

1.1 General

1.1.1 Steel Sandwich Materials used for the construction or repair of marine structures which are classed or certified or are intended for classification or certification by LR, are to be manufactured, tested and inspected in accordance with the Rules for Materials and the Sandwich Construction Rules.

1.1.2 The material grade of the perimeter bars are to comply with the requirements of *Table 2.2.1 Material classes and grades* in *Pt 3, Ch 2 Materials* of the Rules for Ships for secondary structures.

1.1.3 Non-metallic core materials are to be applied, tested and certified in accordance with this Chapter of the Sandwich Construction Rules.

1.1.4 The methods of construction are to be in accordance with the Sandwich Construction Rules.

1.2 Electrical continuity

1.2.1 For protection against the possibility of electric shock in the event of an electrical earth fault, electrical continuity of the ship's metallic structure is to be ensured. Metallic parts of structural panels and members are to be effectively earthed to the ship's hull, if necessary by means of dedicated robust earthing conductor(s) having a cross-sectional area of not less than 16 mm^2.

Section 2
Core material

2.1 Scope

2.1.1 The requirements of this section make provision for the *in situ* production of a solid elastomeric material between two steel plates thus forming a steel sandwich panel.

2.1.2 The elastomer properties when, tested to a suitable standard, shall be agreed with LR and formed *in situ* by use of base components approved by LR.

2.1.3 The base component manufacturer must hold valid LR certification, based on an agreed schedule of tests and inspection of his facilities and quality control procedures.

2.1.4 The mixing of the base components and the injection of the mix to form the elastomer is to be carried out according to a written procedure approved by LR.

2.1.5 Base components are to be provided with unique identifications by their manufacturers.

2.1.6 No batch is to be used later than its date of expiry, except with the prior agreement of LR and new certificate of conformity being obtained from the base component manufacturer.

2.1.7 The Builder is to ensure that batches are stored in accordance with the manufacturer's instructions and are used systematically and sequentially.

2.2 Submission of information

2.2.1 The following information is to be submitted by the Design Organisation:

(a) Material specifications and tolerances.
(b) Listing of materials used.
(c) Method and site of manufacture, and suppliers of components.
(d) Evidence of selected manufacturer's or sub-contractor's ability to produce the core material in accordance with the design specification. This shall be confirmed in each case by an agreed schedule of tests representative of the production being carried out in the presence of an LR Surveyor.

2.2.2 It is the responsibility of the Design Organisation to ensure that materials and components are available to the appropriate specification prior to commencement of manufacture.

2.3 Core material certification

2.3.1 The base component manufacturer is to provide the Builder with certificates of conformity for each batch of material supplied indicating the relevant values specified in *Ch 2, 2.5 Material testing*. These values are to comply with those specified by the approved specification.

2.3.2 The Builder is to ensure copies of certificates of conformity (which must indicate the actual tested values) are obtained for batches of materials received, and is to maintain accurate records. LR may at any time select a sample of a material for testing by an independent source and should such tests result in the material failing to meet specification, the batch will be rejected.

2.4 Material storage

2.4.1 For incoming base materials, irrespective of whether or not the Builder conducts his own tests or is reliant on the manufacturer for certificates of conformity the following is to be carried out, where applicable, on receipt of any material.

(a) The consignment is to be divided into its respective batches and each batch is to be labelled accordingly.
(b) Each batch is to be visually examined for conformity with the batch number, visual quality and expiry date.
(c) Each batch is to be separately labelled and stored accordingly.
(d) Each unit within the batch is to be labelled with the batch number.
(e) Written records are to be maintained of the above and these are to be cross-referenced with the certificate of conformity for the material and/or the Builder's own test results.

2.4.2 Ready use components are to be maintained in stirred tanks at the temperatures recommended by the manufacturer. If these are above ambient then suitable calibrated temperature measuring devices are to be maintained.

2.5 Material testing

2.5.1 The elastomer is currently based on polyurethane technology, hence the following tests should be conducted on the base components by the manufacturer:

(a) Polyol
    (i) Viscosity
    (ii) Moisture content (*see* Note)
    (iii) Hydroxyl value
(b) Iso-cyanate
    (i) Viscosity
    (ii) Iso-cyanate value

Note The requirement for moisture content test may be withdrawn providing the manufacturer provides written evidence the polyol contains a suitable moisture scavenging system.

2.5.2 The builder of the sandwich panels must mix the individual components of the elastomer under controlled conditions and measure the following properties according to recognised standards to a schedule acceptable to LR:

(a) Density
(b) Hardness

(c) Shear modulus
(d) Tensile stress
(e) Tensile strain to failure
(f) Bond shear strength.

2.5.3 Recognised standards to which specimens of elastomer are to be tested are listed in *Table 2.2.1 Cured elastomer properties*. In addition, if the deviation of one result exceeds the mean by more than two standard deviations, that result is to be discarded and one further specimen tested, *see also Figure 2.2.1 Cured elastomer properties*. If a total of three specimens fail then the batch will be rejected.

Table 2.2.1 Cured elastomer properties

Test	Standard	Criteria
Density	ISO 845	≥ 1000 kg/m^3 at RT
Hardness	DIN 53505	Shore D≥65 at RT
Shear modulus	Torsion pendulum test –20°C to +80°C DIN EN ISO 6721-2	G≥312-2.4T (°C)
Tensile stress	ISO 527 or ASTM D412	≥20MPa at RT ≥5MPa at +80°C
Elongation	ISO 527 or ASTM D412	Min. 10% at –20°C Min. 20% at RT
Bond shear strength	ASTM D429-81	≥2.7MPa (shot strength blasted) ≥4MPa (grit blasted)
RT = Room temperature in °C		

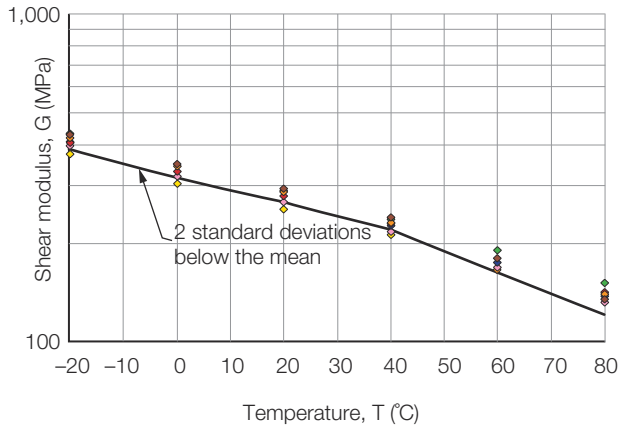


Figure 2.2.1 Cured elastomer properties

■ *Section 3*
Panel manufacturing process

3.1 General

3.1.1 This Section includes the minimum requirements for the elastomer and its base components at the time of installation.

3.1.2 Where pumping equipment is used it is to be maintained in accordance with the manufacturer's instructions. A valid certificate of calibration is to be retained in the quality control documentation to confirm the accuracy of the equipment.

3.1.3 Metered mixing equipment is to be calibrated for the mix quantities prior to the commencement of production, and at scheduled times thereafter subject to a minimum of one per shift.

3.2 Workmanship

3.2.1 The general level of workmanship, where no detailed requirements are given in this Chapter, is to be to the Surveyor's satisfaction.

3.3 Preparation of steel

3.3.1 The cavity surfaces are to be clean and dry, free from surface rust, degreased and grit free.

3.3.2 A minimum surface roughness of 60 microns and cleanliness to Swedish Standard Sa2.5 is to be achieved on the bonding surfaces before injection of elastomer. Alternative surface finishes will only be considered on an individual basis and will require validation by an agreed test program.

3.3.3 In general major structural welds are to be completed before injection into the cavity. These include lashing pots and other cargo securing details, and where highly loaded structural arrangements, such as crane foundations are welded directly to the sandwich support members.

3.3.4 Perimeter bars are to be welded on to the bottom plate in accordance with the construction plans to form the cavity walls. Any welds in way of the perimeter bars are to be ground smooth. *See Ch 2, 6 Welding* for welding requirements.

3.3.5 The required core thickness is to be maintained by spacers made of steel or elastomer or by any other suitable method arranged on the bottom plate in accordance with the design documentation.

3.3.6 Lifting arrangements are to be designed such that the steel plates and the finished sandwich panels are subjected to minimal distortion and unnecessary loads. Panels are to be adequately supported until the injected elastomer has cured to avoid distortion.

3.3.7 In general welding of the cavity being injected and cavities immediately adjacent is to be completed prior to any elastomer injection.

3.4 Elastomer preparation, identification and characterisation

3.4.1 The material components are to be checked by the Builder, prior to injection, to ensure that the material base component's batch test certificates meet the requirements.

3.4.2 For each batch of material a minimum of three Shore D hardness tests are to be carried out on the cured elastomer injected on-site in accordance with DIN 53505. Each batch is to comply with the following (average of the results):

(a) Shore D > 65 at room temperature.

3.4.3 The test samples may be prepared by any of the following methods:

(a) an injection bucket shot preferably cured for 24 hours.
(b) the centre of a 40 mm thick elastomer core cured for 24 hours, prepared from injection into a large mould at room temperature.
(c) hand mixed components cured in a small heated mould according to specified time-temperature profile (130°C for at least 1 hour), tested at least 1 hour after removal from mould, at room temperature.

3.4.4 The pot life for each batch of the elastomer is to be determined by a test sample. A pot life between 360 – 450 seconds is to be achieved. Care is to be taken to ensure that the pot life is greater than the time it takes to fill the cavity.

3.4.5 The pot life sample core is to be visually examined and is to be free from surface defects and blemishes.

3.4.6 If the Surveyor has any cause for concern over the tests listed in this section or the batch properties, he may at any time, require samples of both elastomer and adhesion to steel samples to be prepared and tested.

3.5 Preparation for cavity injection

3.5.1 Venting and injection holes are to be located in the top plate as shown on the design documentation.

3.5.2 The cavity formed by the steel plates and perimeter bars is to be air tight. Air tightness is to be demonstrated to the Surveyor's satisfaction, according to a mutually agreed schedule, prior to elastomer injection. When this test is performed, the procedure given in *Pt 3, Ch 1, 9.6 Leak test procedures* of the Rules for Ships are to be followed with the exception of that relating

to the air pressure. It is recommended that the air pressure be raised to 0,2 bar (0,2 kgf/cm^2) and kept at this level for about one minute. Any failed welds are to be repaired and retested.

3.5.3 Panel restraint beams are to be arranged in accordance with the design documentation.

3.5.4 Prior to any injection the relative humidity in the cavity is to be determined to confirm freedom from moisture. This process and the method to be used is to be part of the design documentation.

3.6 Cavity injection

3.6.1 Injection is to be carried out when the cavity is deemed satisfactory as described above.

3.6.2 The top and bottom plates are required to maintain a temperature of not less than 50°C measured by contact thermocouple for a duration of 30 minutes in order to achieve satisfactory bonding of the elastomer to the steel. Depending on the ambient conditions it may be necessary to cover the sandwich panel with thermal blankets.

3.7 Post injection

3.7.1 After completion of the injection, the injected elastomer is to be tested and the Surveyor is to witness the test. For each panel a minimum of one levelling funnel is to be Shore D Hardness tested after injection. The results are to comply with the requirement given in *Ch 2, 3.4 Elastomer preparation, identification and characterisation 3.4.2*.

3.7.2 After the injected elastomer has cured, the holes for high temperature pressure relief valves are to be drilled in accordance with the construction procedure report. In certain circumstances depending on the application, e.g. bottom shell, holes are not to be drilled.

3.7.3 The injection and venting holes are to be sealed by welding a steel disk into each hole.

3.7.4 Voids are to be brought to the attention of the Surveyor. The size of voids may be determined by tap-testing. The design documentation is to define the maximum allowable void size.

3.8 Repair

3.8.1 Voids larger than the maximum void size are to be repaired. Repairs are to be agreed with the Surveyor prior to being carried out.

3.8.2 The repair procedure is to be defined in the design documentation.

3.8.3 When modifications or repairs are required, that result in a procedure, which is different to the procedures given in the design specification, these procedures are to have prior agreement of the Surveyor.

3.8.4 Welding is to be carried out in accordance with the approved welding procedure, *see Pt 3, Ch 10, 2.7 Welding procedures and welder qualifications* of the Rules for Ships.

■ *Section 4*
Additional procedures for overlay construction

4.1 General

4.1.1 Provisions are made in this Section for the construction of sandwich panels by overlay construction.

4.1.2 This Section contains requirements for overlay construction and is applied in addition to the requirements of *Ch 2, 3 Panel manufacturing process*, as appropriate.

4.1.3 Overlay construction is only to be applied when the average gauged thickness after diminution is equal to or greater than 50 per cent of the rule original plate thickness. *See also Ch 1, 1.5 Special application* for special application.

4.2 Preparation of existing steel surface

4.2.1 After blasting, incidental cracks or holes are to be repaired to an approved crop/repair procedure prior to commencement of construction.

4.2.2 For overlay construction attaching the perimeter bars to the existing plating by methods other than welding will be specially considered.

Section 5
Typical design details

5.1 General

5.1.1 Typical design details are provided in this Section.

5.1.2 The design detail should be arranged to transfer loads effectively into the surrounding structure, whilst maintaining acceptable stress levels.

5.1.3 Care is to be taken to ensure that structural continuity is maintained, the detail is smooth and proper alignment is achieved. Special care is to be taken in the design and positioning of perimeter bars. Unless otherwise agreed the perimeter bar should be positioned above stiffening members.

5.2 Application

5.2.1 The detail designs provided in this Section are applicable to all ship types covered by the Sandwich Construction Rules.

5.2.2 Where suggested values are indicated regarding geometries or scantlings, these are given as guidance.

5.3 Alternative arrangements

5.3.1 In cases where detailed requirements are not given, specific solutions are to be based on the principles of this Section and submitted for appraisal.

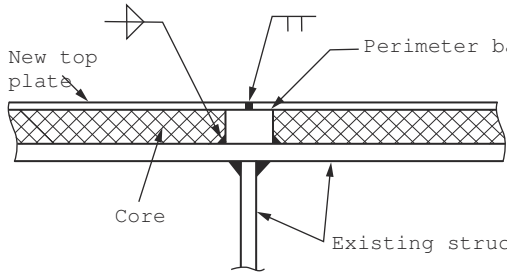
5.3.2 Alternative structural arrangements may be acceptable provided it can be demonstrated through a Finite Element Assessment that a satisfactory performance will be maintained.

5.4 Typical design details

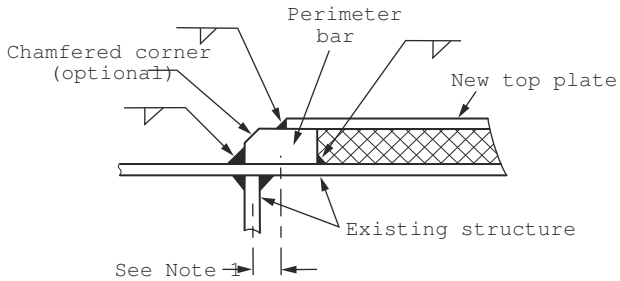
5.4.1 Design details for overlay construction are in general to be in accordance with *Table 2.5.1 Overlay construction design details for structural items*.

5.4.2 Design details for sandwich new construction are in general to be in accordance with *Table 2.5.4 Design details for new construction* .

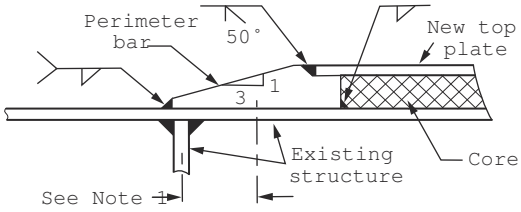
Table 2.5.1 Overlay construction design details for structural items



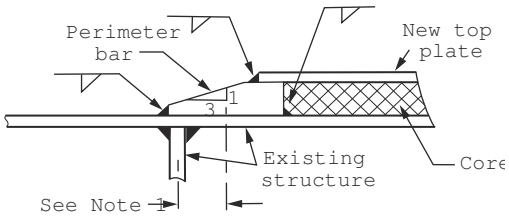
OS1: Perimeter bar – Adjacent pane



OS2: Perimeter bar – Clear of traffic (see Note 1)

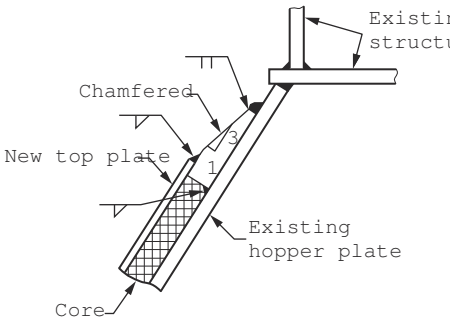


Recessed Top Plate

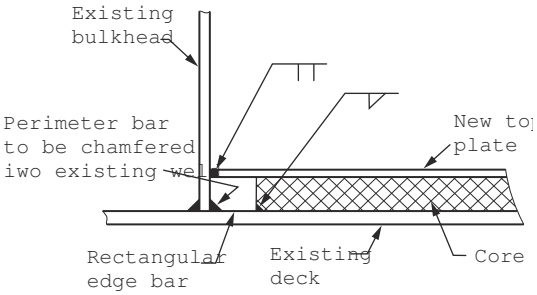


Lapped Top Plate

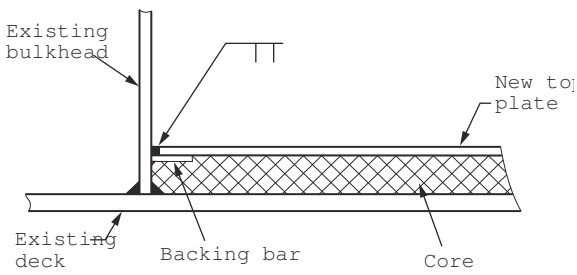
OS3: Perimeter bar – In way of traffic (see Note 1)



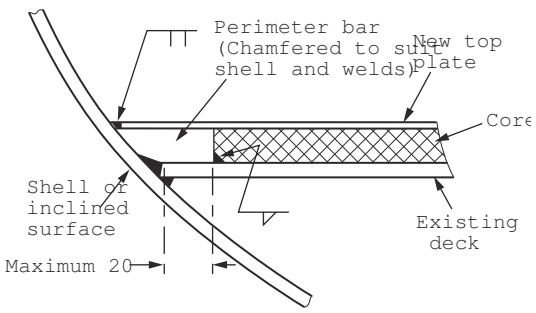
OS4: Upper edge of bulkhead stc



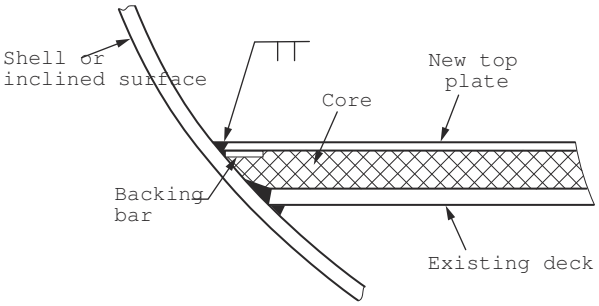
OS5: Abutting vertical surface – Perim



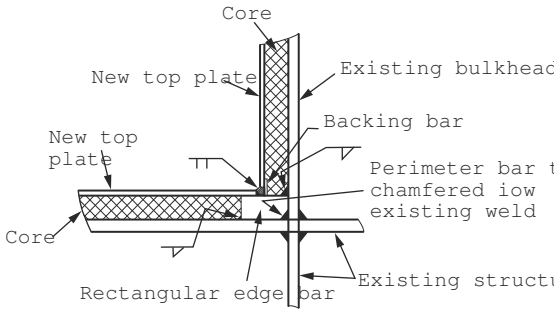
OS6: Abutting vertical surface – backir



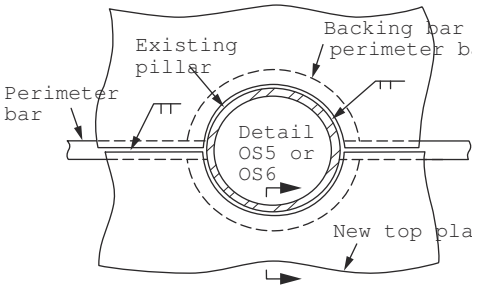
OS7: Abutting iclined surface – perim



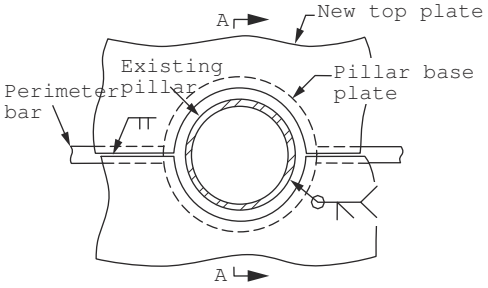
OS8: Abutting inclined surface – backing

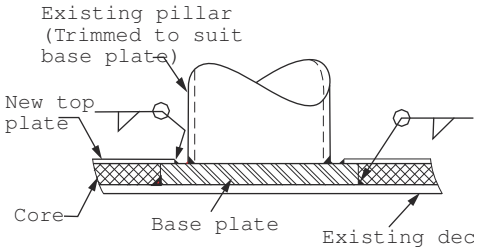


OS9: Abutting vertical sandwich surface – p



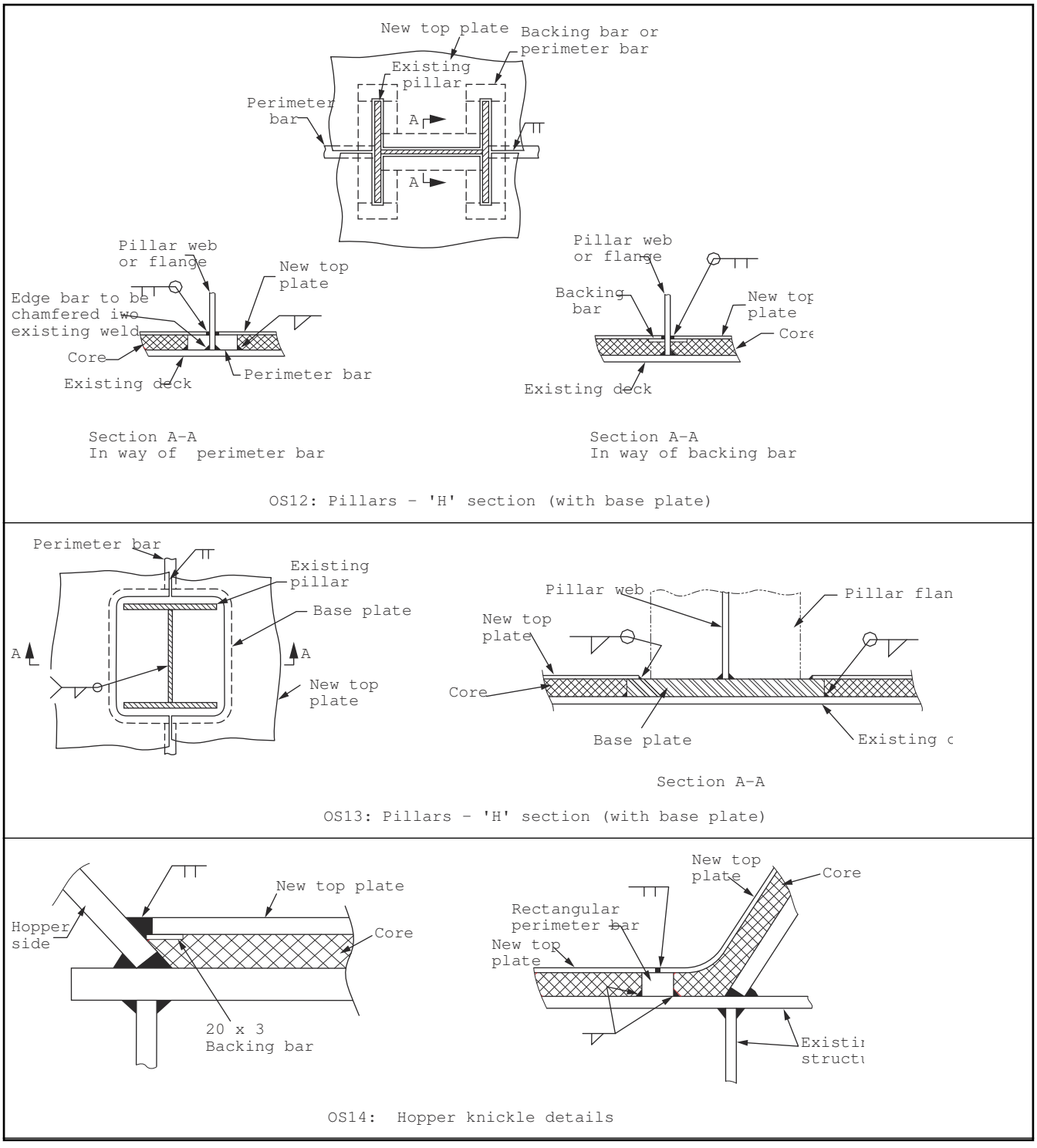
OS10: Pillars – round (without bas





Section A–A

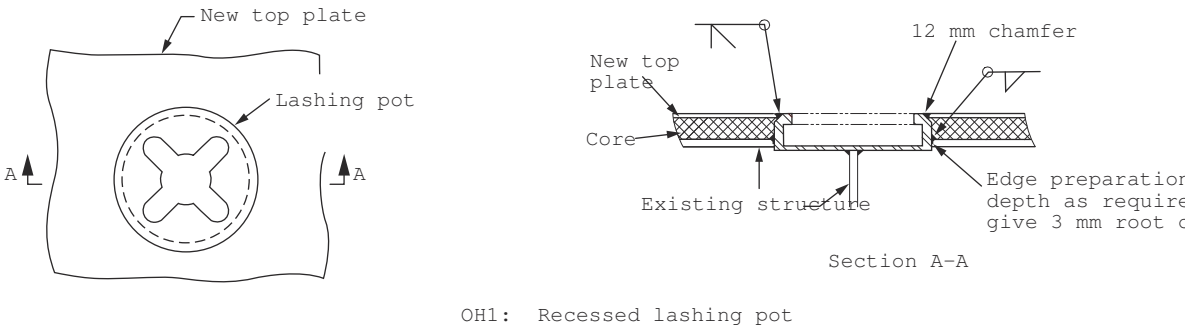
OS11: Pillars – round (with base plate)



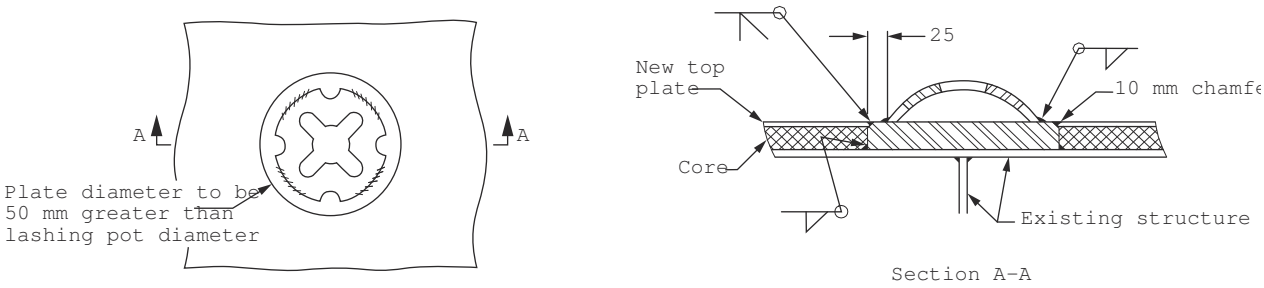
5.5 Primary steel support members

5.5.1 The scantling requirements for primary steel support members are given in *Ch 4 Design Basis and Scantling Determination of Primary Structure*.

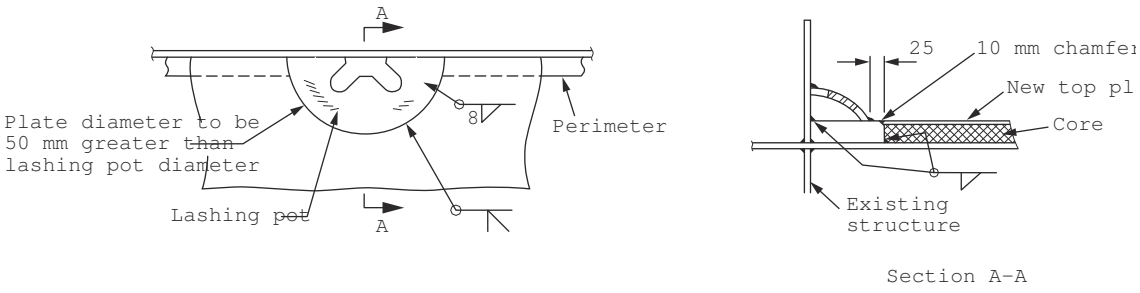
Table 2.5.2 Design details for hull outfitting items



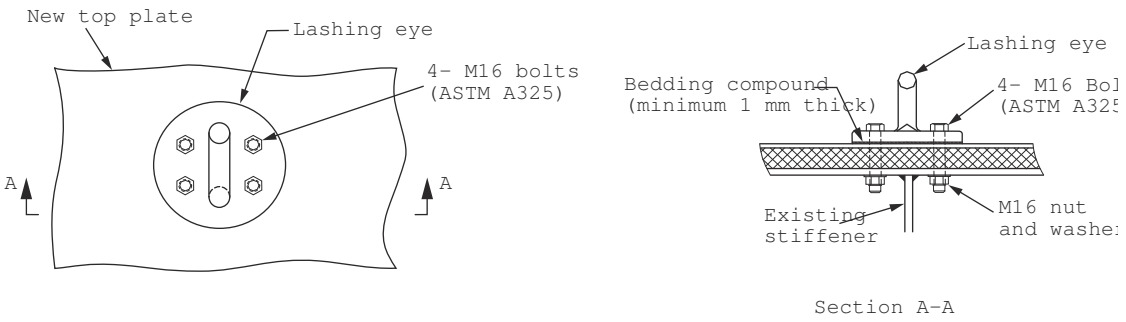
OH1: Recessed lashing pot



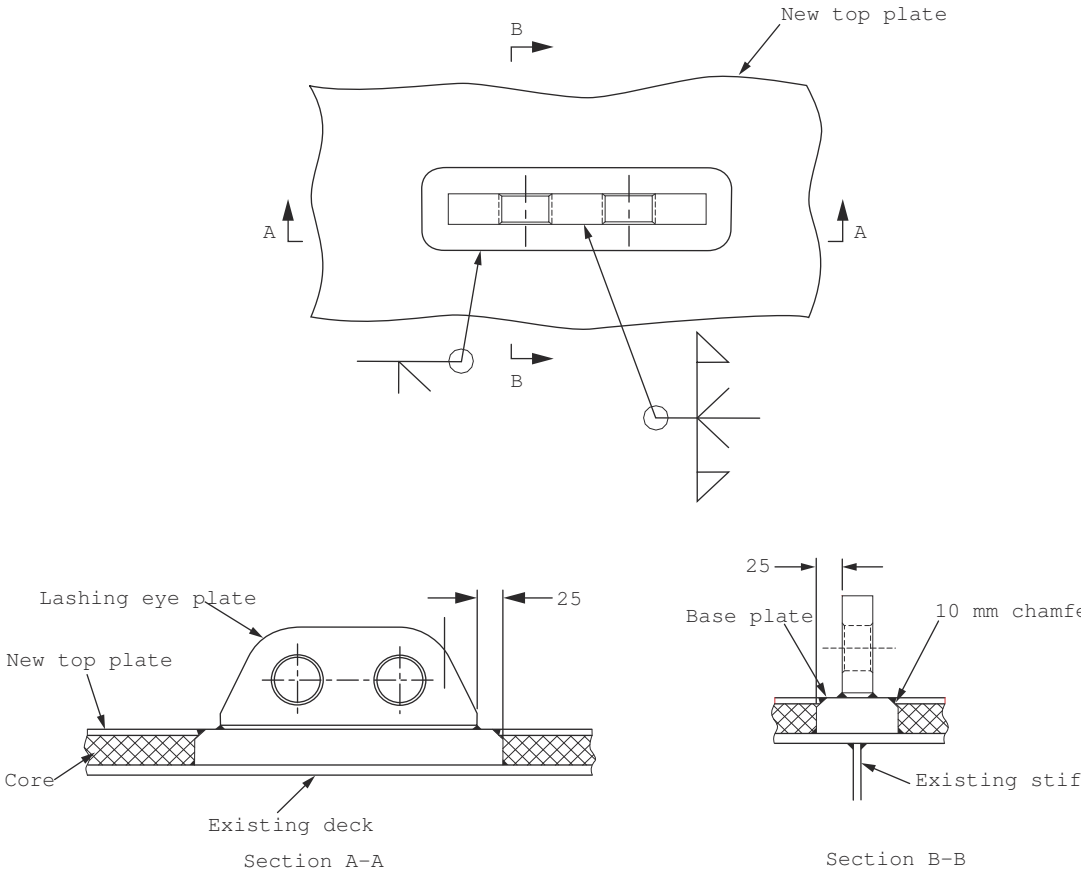
OH2: Raised dome (mid-panel)



OH3: Raised half dome (panel edge)

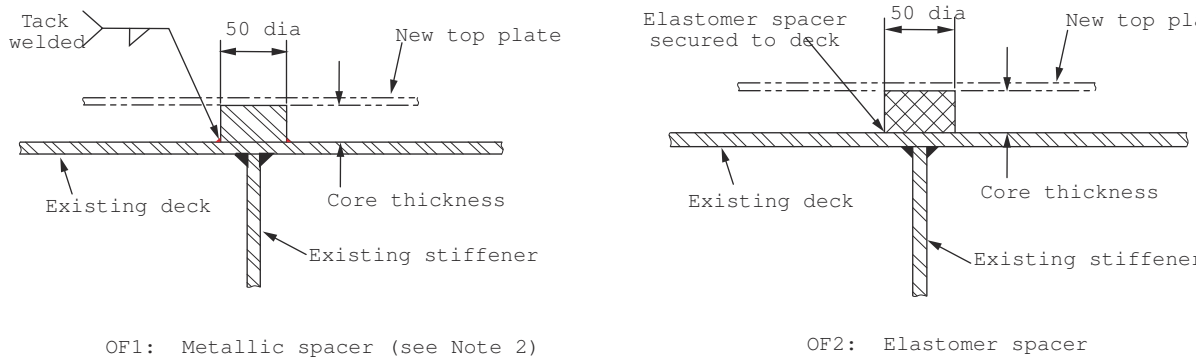


OH4: Lashing eye bolted



OH5: Lashing eye plates

Table 2.5.3 Design details for fabrication



OF1: Metallic spacer (see Note 2)

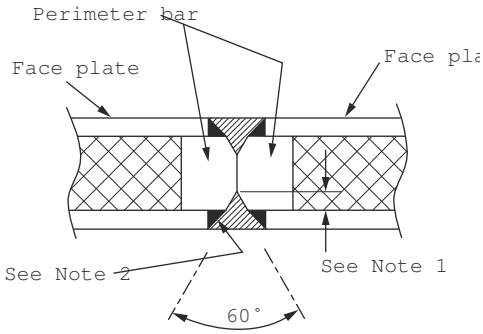
OF2: Elastomer spacer

Note 1. Location of the perimeter bar relative to existing longituindal or transverse member can be varied according to the design of the overlay.

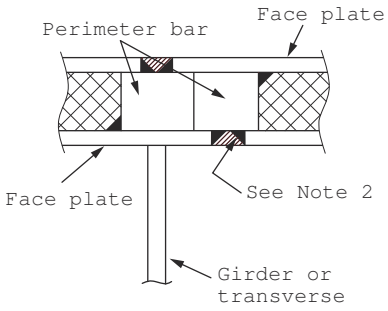
Note 2. Generally tack welding is not to be carried out on higher tensile steel plates.

Note 3. Welding to be as required in *Ch 2, 6 Welding*.

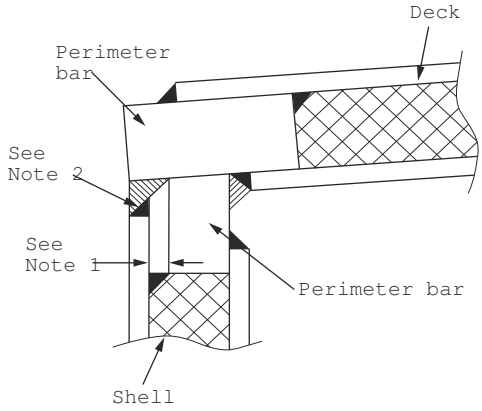
Table 2.5.4 Design details for new construction

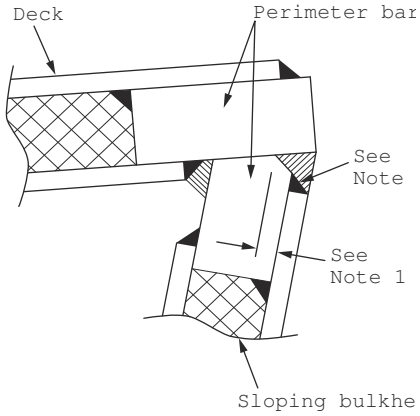


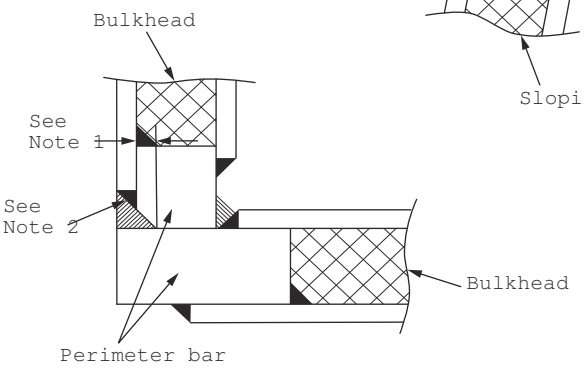
NS1: Perimeter bar – adjacent pa
(see Notes 1, 2 and 3)



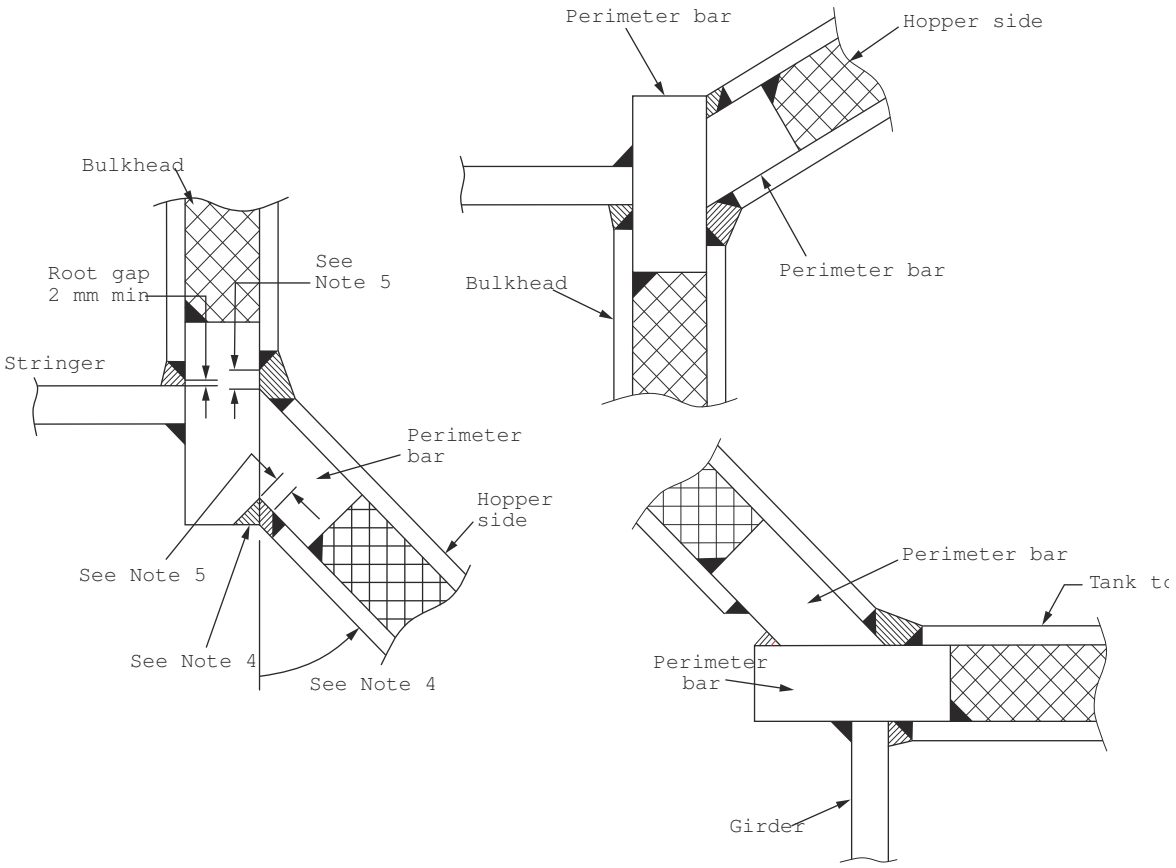
NS2: Perimeter bar – adjacent panels in v
steel support members or bulkheads
(see Notes 1 and 2)



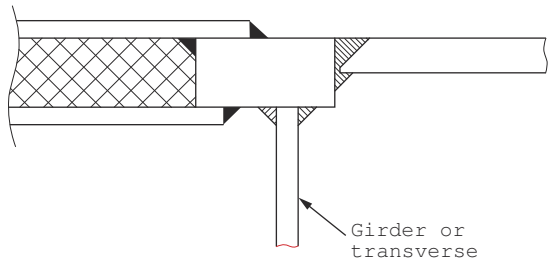




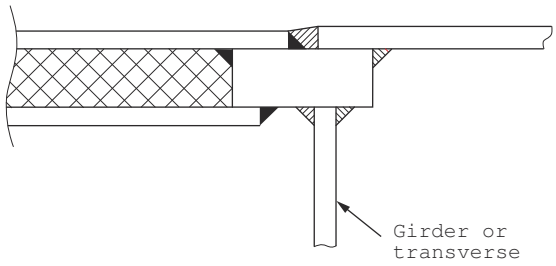
NS3: Perimeter bar – Deck shell and bulkhead connection (see Notes 1 an



NS4: Perimeter bar – Deck and sloping bulkhead connection (see Notes 1, 2, 4



NS5: Sandwich panel abutting single panel s
(see Note 6)



NS6: Sandwich panel abutting single panel s
(see Note 6)

Note 1. Chamfered preparation on perimeter bar to be at least the thickness of the steel face plates.

Note 2. Weld between face plates and perimeter bar to be made as part of panel pre-fabrication, prior to joining panels.

Note 3. Only in way of pillar bulkheads.

Note 4. If the angle is less than 45°, chamfer is required.

Note 5. In general, the root gap is to be equal to the thickness of the largest adjacent faceplate thickness.

Note 6. A taper of not less than 4:1 is to be adopted and additional stiffening may be required when utilised in way of hull girder. Not permitted for transverse butts in the strength deck and bottom plating.

Section 6
Welding

6.1 General

6.1.1 The requirements for welding in *Pt 3, Ch 10 Welding and Structural Details* of the Rules for Ships are to be applied as applicable.

6.1.2 Welding to the face plates of injected steel sandwich panels can be carried out, provided that any effect of heat input on the elastomer does not affect the capacity of the panel. The design documentation submitted in accordance with *Ch 1, 7.1 General* is to include details of how the effects of heat input will be addressed.

6.1.3 If pre-fabricated panels are to be employed, welding to the face plates can be carried out, provided that any effect of heat input on the elastomer does not affect the capacity of the panel. The design documentation submitted in accordance with *Ch 1, 6.1 Plans to be submitted 6.1.6* is to include details of how the effects of heat input will be addressed.

6.1.4 Minor temporary attachments, cable trays, and small pipe clamps etc. can be welded directly to the top or bottom plate without the use of internal reinforcing plates. Any defects in the structure resulting from the removal of temporary attachments are to be repaired.

6.1.5 Attention is to be given to the examination of the plating in way of the minor welding carried out to ensure:

(a) freedom from cracks; and

(b) for each weld there are no voids present larger than the maximum void size, *see Ch 2, 3.7 Post injection 3.7.4*.

6.1.6 In areas subject to high stress, deep penetration or full penetration welding may be required.

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CHAPTER 3 DESIGN BASIS FOR PANELS

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SECTION 3 PANEL SCANTLING REQUIREMENTS – DECKS LOADED BY WHEELED VEHICLES

SECTION 4 PANEL SCANTLING REQUIREMENTS

SECTION 5 OVERLAY SCANTLING REQUIREMENTS

SECTION 6 MINIMUM THICKNESS

SECTION 7 BUCKLING

CHAPTER 4 DESIGN BASIS AND SCANTLING DETERMINATION OF PRIMARY STRUCTURE

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2 **Panel scantling requirements – bulkheads**

3 **Panel scantling requirements – decks loaded by wheeled vehicles**

4 **Panel scantling requirements**

5 **Overlay scantling requirements**

6 **Minimum thickness**

7 **Buckling**

Section 1
General

1.1 Application

1.1.1 The requirements of this Chapter are applicable to steel sandwich panels used in the construction of bulkheads, shell envelopes, and deck structure.

1.1.2 To determine the required scantlings for sandwich panels, the formulae given in the Rules for Ships are, in general, to be used.

1.2 Equivalent requirements

1.2.1 LR will consider direct calculations for the derivation of scantlings as an alternative and equivalent to those derived by the Steel Sandwich Construction Rules requirements.

Section 2
Panel scantling requirements – bulkheads

2.1 General

2.1.1 The requirements of this Section cover watertight and deep tank transverse and longitudinal bulkheads.

2.1.2 The buckling requirements of *Ch 3, 7 Buckling* are also to be satisfied.

2.2 Watertight and deep tank bulkheads

2.2.1 The top and bottom plate thickness of the steel sandwich panel are to be determined in accordance with *Ch 3, 2.2 Watertight and deep tank bulkheads 2.2.2*. For a deep tank bulkhead an allowance of 2,5 mm is to be added to the face plate thicknesses of the sandwich plate determined in *Ch 3, 2.2 Watertight and deep tank bulkheads 2.2.2*. The allowance is to be apportioned according to the location of the bulkhead and type of cargo on either side of the bulkhead. The allowance may be increased depending on the nature of the cargo.

2.2.2 The steel sandwich panel for watertight and deep tank bulkheads is to be dimensioned such that the requirement below is satisfied:

(a) watertight bulkhead

$$d_T^2 - t_c^2 \geq \frac{0,04}{\sigma_o} \alpha h_4 b^2$$

(b) deep tank bulkhead

$$d_T^2 - t_c^2 \geq \frac{0,04}{\sigma_o}\left(\frac{\alpha\ \rho\ h_4 b^2}{1,025}\right)$$

where

d_T = total thickness of the sandwich panel, in mm

= $t_c + t_{n1} + t_{n2}$

σ_o = specified minimum yield stress in N/mm^2 of the face plates

α = *see Table 3.2.1 Coefficient α*

ρ = relative density (specific gravity) of liquid carried in a tank but is not to be taken less than 1,025

h_4 = *see Table 1.9.1 Watertight and deep tank bulkhead scantlings* in Pt 4, Ch 1 of the Rules for Ships.

t_{n1} = net thickness of the top plate, in mm

t_{n2} = net thickness of the bottom plate, in mm

= *a*, *b* as defined in *Ch 1, 7.2 Symbols*.

Table 3.2.1 Coefficient α

a/b	1,0	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	2,0	>2,0
α	0,0513	0,0581	0,0639	0,0687	0,0726	0,0757	0,0780	0,0799	0,0812	0,0822	0,0829	0,0833

2.2.3 The bond shear capacity of a panel is to satisfy the following criteria:

$$t_c + t_{n1} + t_{n2} \geq \frac{\beta\ \gamma\ q b}{\tau_c}$$

where

q = $0,01\left(\frac{\rho\ h_4}{1,025}\right)$ in N/mm^2 where the bulkhead is a deep tank

= $0,01 h_4$ in N/mm^2, where the bulkhead is a watertight bulkhead

β = $0,1\frac{a}{b} + 0,65$

γ = *see Table 3.2.2 Coefficient γ*

τ_c = 6 MPa.

= *a*, *b* as defined in *Ch 1, 7.2 Symbols*.

Table 3.2.2 Coefficient γ

a/b	1,00	1,25	1,50	1,75	2,0	>2,0
γ	0,44	0,49	0,52	0,52	0,52	0,50

2.2.4 The ultimate bending capacity of the sandwich panel is to be assessed by the method in *Ch 3, 2.2 Watertight and deep tank bulkheads 2.2.5*. This is only applicable for sandwich panels subjected to lateral pressure.

2.2.5 The ultimate bending capacity, q_u, is to be taken as:

$$q_u = \frac{24\left(\frac{a}{b}+1\right)}{b^2\left(1,5\frac{a}{b}-0,5\right)}\ \frac{d_T^2 - t_c^2}{4}\ \sigma_o\ \text{N/mm}^2$$

2.2.6 The ultimate bending capacity, q_u, calculated in *Ch 3, 2.2 Watertight and deep tank bulkheads 2.2.5* is to satisfy the following criteria:

$$q_u \geq \eta q$$

where

$$\eta = 1,5$$

2.2.7 The thicknesses of the core, top and bottom plates are not to be less than:

(a) Deep tank bulkheads

$$t_c = 20 \text{ mm}$$

$$t_{n1}, t_{n2} = 4,5 \text{ mm where } L < 90 \text{ m}$$

$$= 5,0 \text{ mm where } L > 90 \text{ m}$$

(b) Watertight bulkheads

$$t_c = 20 \text{ mm}$$

$$t_{n1}, t_{n2} = 3,0 \text{ mm.}$$

2.2.8 Stiffeners, stringers or webs supporting vertical or horizontal stiffening are to be in accordance with the requirements in *Pt 4, Ch 9, 9 Primary members supporting longitudinal framing* of the Rules for Ships.

2.2.9 Where tanks are intended for liquid cargoes of a special nature the scantlings and arrangements will be considered in relation to the nature of the cargo.

Section 3
Panel scantling requirements – decks loaded by wheeled vehicles

3.1 Application

3.1.1 The requirements of this Section cover decks loaded by wheeled vehicles and are in addition to the requirements in *Pt 3, Ch 9, 3 Decks loaded by wheeled vehicles* of the Rules for Ships with the exception of 3.4.1 to 3.4.3 and 3.5.

3.2 Decks loaded by wheeled vehicles

3.2.1 The deck plate thickness is to be not less than:

$$t_1 = t_{n1} + t_{a1}$$

$$t_2 = t_{n2} + t_{a2}$$

where

$$t_{a1}, t_{a2} = 1,5 \text{ mm for strength deck, weather decks, decks forming crown of tank, inner bottom}$$

$$= 1,0 \text{ mm for internal decks elsewhere.}$$

The thicknesses t_{n1}, t_{n2} are to be selected so that the criteria in *Ch 3, 3.2 Decks loaded by wheeled vehicles 3.2.4* are satsfied.

3.2.2 The bending stress, σ_b, in the panel subjected to wheeled vehicles is to be taken as:

$$\sigma_b = \frac{\alpha_w P_1}{\left(\frac{d_T^3 - t_c^3}{6 d_T}\right)} \quad \varphi \quad \text{N/mm}^2$$

where

$$\alpha_w = \left[\left(C_1 t_{n-av} + C_2\right)t_c + C_3 t_{n-av} + C_4 + \left(C_5 s + C_6\right) + C_7\left(\frac{w}{l}\right)^2 + C_8\left(\frac{w}{l}\right) + C_9\right]10^{-3}$$

Φ = $\frac{500}{m}$ where the wheel load is assumed to be adjacent to the girder, *see* Fig. 3.3.1

= 1,0, where the wheel load is assumed to be on the centre of the panel, *see Figure 3.3.1 Diagrammatic illustration of wheel load location and size*

m = width of the wheel load, *see Figure 3.3.1 Diagrammatic illustration of wheel load location and size*

P_1 = corrected patch load, in N

= 9806 $P_w \lambda$

P_w = load, in tonnes, on the tyre print. For closely spaced wheels the tyre print area may be taken as a combined print area

λ = dynamic magnification factor

= 1,25 for harbour conditions

= (1 + 0,7n) for sea-going conditions

n = tyre correction factor, *see Table 3.3.1 Tyre correction factor, n*

w = breadth of panel in the transverse direction

l = length of panel in the longitudinal direction

s = the smaller of w or l

$t_{n\text{-}av}$ = average net thickness

= $\frac{t_{n1} + t_{n2}}{2}$

Coefficients C_1 to C_9 are to be obtained from *Table 3.3.2 Curvature factor coefficients truck wheel loads* or *Table 3.3.3 Curvature factor coefficients car wheel loads* for truck wheel loads and car wheel loads respectively.

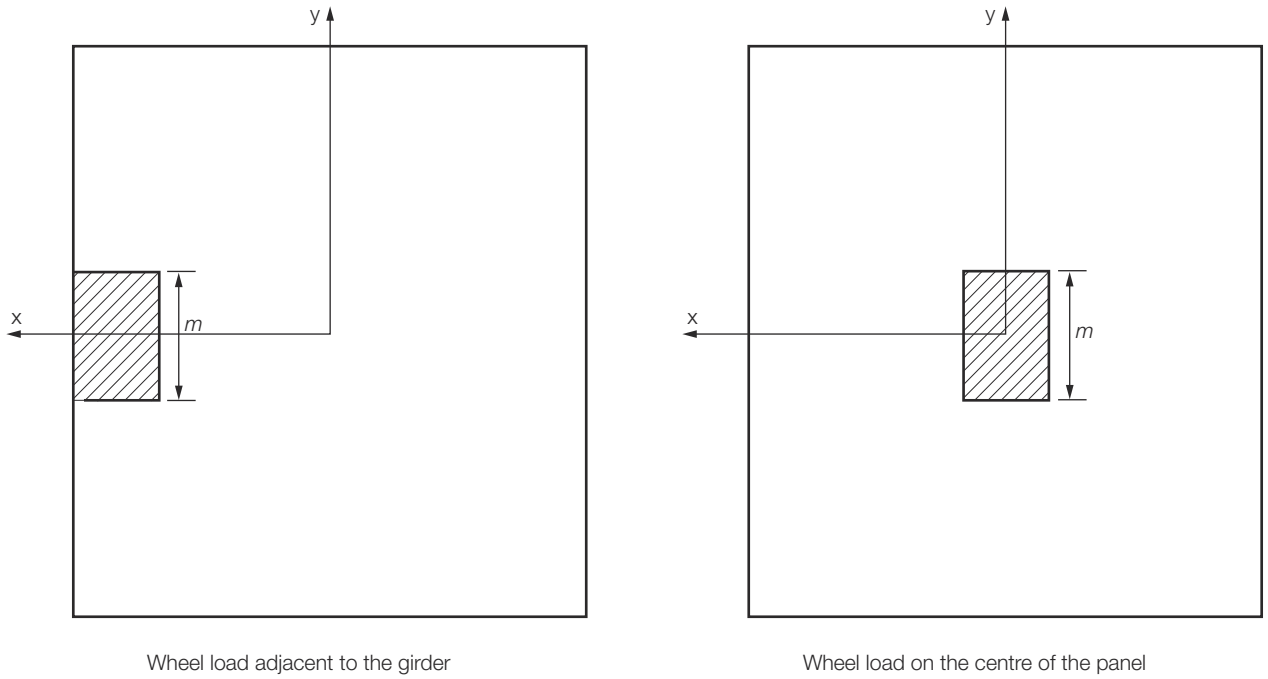

Figure 3.3.1 Diagrammatic illustration of wheel load location and size

Note The details shown in this figure are for illustration purposes only

Table 3.3.1 Tyre correction factor, *n*

Number of wheels in idealised patch	Pneumatic tyres	Solid rubber tyres	Steel or solid tyres
1	0,6	0,8	1,0
2 or more	0,75	0,9	1,0

Table 3.3.2 Curvature factor coefficients truck wheel loads

Aspect Ratio, *w/l*	Short span, *s*, mm	t_{n1}, t_{n2} mm	Coefficients								
			C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Single axle configuration, wheel load at center											
w/l > 1,0	2000 ≤ *s* ≤ 2500	3	0,3	–0,2	8	150	0,04	–80	–35	130	–95
	2000 ≤ *s* ≤ 3000	4,5									
	2000 ≤ *s* ≤ 3500	6,8,10	0,3	–0,2	8	150	0,04	–80	–35	130	–95

$0,5 \le w/l \le 1,0$	$2000 \le s \le 2500$	3	0,3	–0,2	8	150	0,04	–80	–	–	–
	$2000 \le s \le 3000$	4,5									
	$2000 \le s \le 3500$	6,8,10	0,3	–0,2	8	150	0,04	–80	–	–	–
Double axle configuration, wheel load at center											
$w/l > 1,0$	$s = 2500$	4	0	1,6	22	100	0,04	–100	–35	130	–95
	$2500 \le s \le 3000$	5									
	$2500 \le s \le 3500$	6	0,3	0,4	8	180	0,04	–115	–45	165	–120
	$2500 \le s \le 3500$	8									
	$3000 \le s \le 3500$	10									
$0,5 \le w/l \le 1,0$	$s = 2500$	4	0	1,6	22	100	0,04	–100	–	–	–
	$2500 \le s \le 3000$	5									
	$2500 \le s \le 3500$	6	0,3	0,4	8	180	0,04	–115	–	–	–
	$2500 \le s \le 3500$	8									
	$3000 \le s \le 3500$	10									
Double axle configuration, wheel load adjacent to transverse girder											
$w/l > 1,0$	$s = 2000$	3	0,8	–1,5	5	140	0,06	–120	–35	130	–95
	$2000 \le s \le 2500$	4									
	$2000 \le s \le 3000$	5									
	$2000 \le s \le 3500$	6	0,6	–0,3	–3	230	0,045	–130	–40	150	–110
	$2500 \le s \le 3500$	8									
	$3000 \le s \le 3500$	10									

$0,8 \le w/l \le 1,0$ use $w/l = 0,8$ if $0,5 \le w/l \le 0,8$)	$s = 2000$	3	0,8	–1,5	5	140	0,06	–120	0	–50	50
	$2000 \le s \le 2500$	4									
	$2000 \le s \le 3000$	5									
	$2000 \le s \le 3500$	6	0,6	–0,3	–3	230	0,045	–130	0	–50	50
	$2500 \le s \le 3500$	8									
	$3000 \le s \le 3500$	10									

Table 3.3.3 Curvature factor coefficients car wheel loads

Aspect Ratio, w/l	Short span, s, mm	t_{n1}, t_{n2} mm	Coefficients								
			C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Single axle configuration, wheel load at center											
$w/l > 1,0$	$2000 \le s \le 3000$	3,4	0,2	0,4	25	200	0,04	–80	–50	185	–135
$0,5 \le w/l \le 1,0$	$2000 \le s \le 3000$	3,4	0,2	0,4	25	200	0,04	–80	–	–	–

3.2.4 The bending stress, σ_b, in *Ch 3, 3.2 Decks loaded by wheeled vehicles 3.2.2* is to be less than

$$\frac{\sigma_o}{k} \ \mathrm{N/mm^2}.$$

■ *Section 4*
Panel scantling requirements

4.1 Application

4.1.1 The requirements of this Section are applicable to steel sandwich panel construction, except for bulkheads and decks loaded by wheeled vehicles where *Ch 3, 2 Panel scantling requirements – bulkheads* and *Ch 3, 3 Panel scantling requirements – decks loaded by wheeled vehicles* is applicable respectively.

4.2 General

4.2.1 In this Section the scantling requirements for the top and bottom plates and core of steel sandwich panels are given.

4.2.2 The thickness of the top and bottom plates of the steel sandwich panels may, in addition, need to be increased to meet the hull girder requirements.

4.3 Taper requirements

4.3.1 The scantlings of the steel sandwich panels are to taper gradually from the midship region to the fore and aft ends, *see Pt 3, Ch 3, 2.5 Taper requirements for hull envelope* of the Rules for Ships. Where it is proposed to taper from steel sandwich panel construction to single steel construction the rule thickness should be used as the basis for the tapering ($t_c = t_{rule}$), *see Ch 3, 4.4 Thickness of sandwich panel 4.4.3* for the calculation of t_{rule} .

4.3.2 Changes in steel sandwich thickness are to be made using a gradual taper.

4.3.3 Where the construction changes from steel sandwich panel to a single steel plate construction a taper of not less than 4:1 is to be adopted and additional stiffening may be required.

4.4 Thickness of sandwich panel

4.4.1 The thickness of the top and bottom plates and core of the steel sandwich panel is to be determined, as shown in *Figure 3.4.1 Determination of equivalent scantlings t_{rule} and Z_{rule}* and in the following paragraphs, on the basis of the equivalent scantlings given in the Rules for Ships (t_{rule} and Z_{rule}).

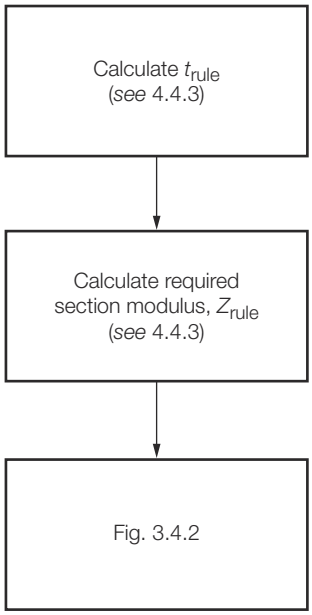

Figure 3.4.1 Determination of equivalent scantlings t_{rule} and Z_{rule}

4.4.2 The top and bottom plate thickness, t_1 and t_2 , of the steel sandwich are to be determined as shown in *Figure 3.4.2 Determination of top and bottom plate thickness and core thickness*. In no case are the thickness of the top and bottom plating and the core thickness to be less than the minimum values given in *Ch 3, 6 Minimum thickness*.

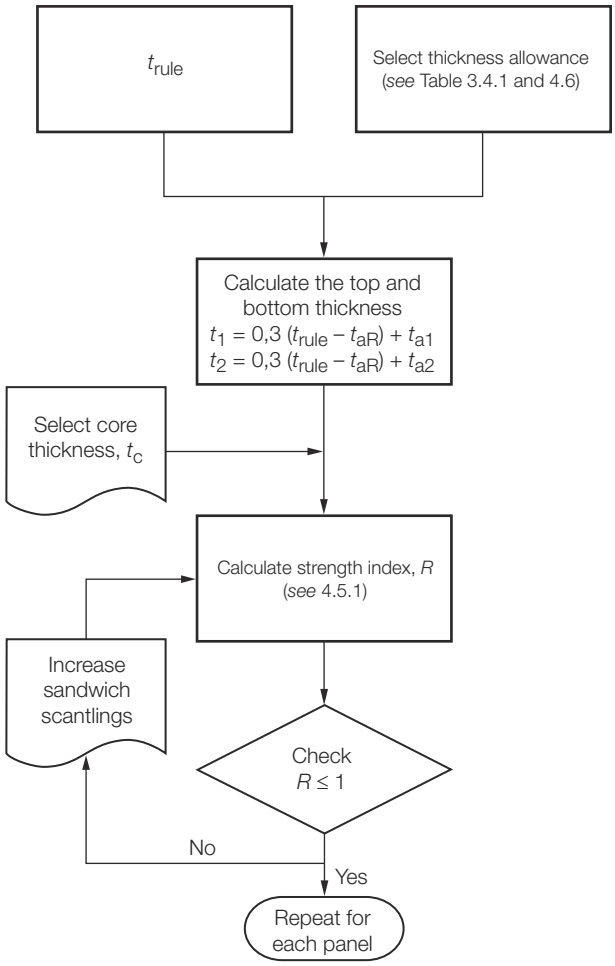

Figure 3.4.2 Determination of top and bottom plate thickness and core thickness

4.4.3 The equivalent rule thickness, t_{rule} , is to be calculated in accordance with the appropriate chapter for the particular ship type. For example, the equivalent rule thickness t_{rule} , for the bottom shell of a General Cargo Ship is to be calculated from *Table 1.5.2 Bottom shell and bilge plating* of the Rules for Ships.

(a) The equivalent rule thickness of the inner bottom plating is to be calculated from *Pt 4, Ch 1, 8.4 Inner bottom plating and stiffening 8.4.1* or *Table 7.8.1 Strengthening for heavy cargo requirements* Item (3)(b) as appropriate and does not include the additions for the protection of steelwork.

4.4.4 The equivalent section modulus, Z_{rule} , of secondary member is to be calculated in accordance with the appropriate chapter for the particular ship type. For example, the equivalent section modulus for the bottom shell longitudinals of a General Cargo Ship is to be calculated from *Table 1.6.1 Shell framing (longitudinal)* in *Pt 4, Ch 1, 6 Shell envelope framing* of the Rules for Ships.

4.4.5 In the calculation of t_{rule} and Z_{rule} the material factor is always to be taken as $k = 1$ and the spacing is always to be taken as $s = 700$ mm.

4.5 Strength index

4.5.1 The steel sandwich panel is to be dimensioned in accordance with the strength index, R, given below. This will ensure that the steel sandwich panel is equivalent to a conventional steel construction:

$$R = 0,01 A_R \left[0,1 \frac{b^2}{d(t_1 + t_2)} + 11,7 \left(\frac{b\, t_c}{d^2} \right)^{1,3} \right] k P_{\text{eq, R}}$$

where

A_R = $\left(\frac{a}{b}\right)^{0,65}$

$P_{eq,R}$ = $0{,}0017\ \frac{Z_{\text{rule}}}{l^2}$ in N/mm^2

l = length of panel, in metres

Z_{rule} = equivalent section modulus, in cm^3, *see Ch 3, 4.4 Thickness of sandwich panel 4.4.4*

t_c = selected core thickness, in mm

a, b, d = *see Ch 1, 7.2 Symbols 7.2.1*

t_1, t_2 = thicknesses of the top and bottom plating, in mm, *see Figure 3.4.2 Determination of top and bottom plate thickness and core thickness*

k = *see Pt 3, Ch 2, 1.2 Steel 1.2.3* of the Rules for Ships.

4.5.2 The strength index for steel sandwich panel is to be such that:

(a) $R \leq 1$

4.6 Thickness allowance

4.6.1 The local thickness allowances for individual structural members are given in *Table 3.4.1 Thickness allowance*. Structural elements not listed in the table, and ships having non-typical structural configurations will be subjected to special consideration.

4.6.2 The thickness allowance is to be applied to the plate thickness in direct contact with the application in *Table 3.4.1 Thickness allowance*. For example the crown of a deep tank which also forms a vehicle deck would have t_a = 2,0 for the top plate and t_a = 2,5 for the bottom plate.

4.6.3 For the protection of steelwork, in addition to the requirements specified in *Ch 3, 5 Overlay scantling requirements*, any ship which is regularly to be discharged by grabs the thickness of the top plating is to be increased by the allowances given below. Inner bottom and hopper plating:

- Continuous wooden ceiling: 2,0 mm
- No continuous wooden ceiling: 3,7 mm

Table 3.4.1 Thickness allowance

Structural elements	t_{aR}	t_{a1}	t_{a2}
Bottom shell	1,0	0,0	1,0
Side shell	1,0	0,0	1,0
Inner bottom, hopper plating	2,0	1,0	1,0
Inner bottom at crown of tank	3,5	1,0	2,5
Strength deck	2,5	2,5	0,0
Internal decks	0,0	0,0	0,0
Superstructure decks	0,0	0,0	0,0
Watertight bulkheads	0,0	0,0	0,0
Deep tank bulkheads	2,5	0,0	2,5
Deep tank crowns which is also a deck	3,5	1,0	2,5
Vehicle deck clear of tanks	2,0	2,0	0,0

Symbols	
t_{aR} =	rule thickness allowance, in mm
t_{a1} =	thickness allowance for the top plate, in mm
t_{a2} =	thickness allowance for the bottom plate, in mm (steel plating to which primary members are attached)

Section 5
Overlay scantling requirements

5.1 Application

5.1.1 The requirements of this Section are applicable to overlay construction.

5.2 Strength index

5.2.1 The overlay construction is to be dimensioned in accordance with the strength index, *R*, given below:

$$R = 0,0125\left[0,1\frac{s^2}{d\left(t_1+t_2\right)} + 11,7\left(\frac{s\,t_c}{d^2}\right)^{1,3}\right]P_{\text{eq}}$$

where

s = spacing of the longitudinals, in mm

P_{eq} = $200\left(\frac{t_{\text{rule}}}{s}\right)^2$ in N/mm^2

t_{rule} = *see Ch 3, 4.4 Thickness of sandwich panel 4.4.3*, in mm

t_c = selected core thickness, in mm

t_1 = thickness of top plating, in mm, not to be less than $t_{1MIN} + t_{a1}$

t_2 = thickness of bottom plating, in mm.

5.2.2 The strength index for the overlay construction is to be such that:

(a) $R \leq 1$

5.2.3 In no case are the thickness of the top plating and the core thickness to be less than the minimum value given in *Ch 3, 6 Minimum thickness*.

Section 6
Minimum thickness

6.1 Application

6.1.1 The minimum thicknesses given in this Section are applicable to new construction and overlay construction.

6.2 Minimum top and bottom plate thickness

6.2.1 The thickness of the top and bottom plate, exclusive of any thickness allowance, is not to be less than as given in *Table 3.6.1 Minimum thicknesses*.

Table 3.6.1 Minimum thicknesses

Item	Minimum thickness in mm	
	New construction	Overlay construction
t_{1MIN}	3,0	3,0
t_{2MIN}	3,0	50% of the as-built thickness

6.3 Minimum core thickness

6.3.1 The thickness of the core is not to be less than:

(a) t_c = 15 mm.

■ *Section 7* Buckling

7.1 General

7.1.1 This Section contains the requirements for buckling control of steel sandwich panels subject to in-plane uni-axial compressive stresses.

7.1.2 In general, all areas of the structure are to meet the buckling strength requirements for the design compressive stresses, *see Ch 3, 7.3 Buckling requirements*.

7.1.3 The buckling requirements are to be met using the thickness of plating less standard deduction for corrosion, d_t , hence any additional thickness for corrosion margin or Owner's extra is not to be included in scantling used to assess the buckling performance.

7.2 Derivation of the buckling stress for steel sandwich panels

7.2.1 The critical compressive buckling stress, σ_E , for a steel sandwich panel subjected to uni-axial in-plane compressive loads is to be derived as follows:

$$\sigma_E = \frac{\pi^2 D f}{l^2\left(t_{p1} + t_{p2}\right)\left(1 - v^2\right)} \text{ N/mm}^2$$

where

$$f = \frac{4}{(1+\mu)^2} \quad \mu \le 1,0$$

$$= \frac{1}{\mu}, \quad \mu > 1,0$$

$$\mu = \frac{\pi^2 D}{\left(1 - v^2\right) l^2 K}$$

$$K = \frac{G_c d^2}{t_c}$$

= *D, v, d, t_c, G_c , see Ch 1, 7.2 Symbols 7.2.1*

l = breadth of panel in the loaded direction, in mm

$t_{p1} = t_1 - t_{corr}$

$t_{p2} = t_2 - t_{corr}$

where

t_{corr} = standard deduction for corrosion, *see Table 4.7.1 Standard deduction for corrosion, d t* in Pt 3, Ch 4 of the Rules for Ships.

7.2.2 Where the elastic critical buckling stress, as evaluated from *Ch 3, 7.2 Derivation of the buckling stress for steel sandwich panels 7.2.1*, exceeds 50 per cent of the specified minimum yield stress of the material, then the buckling stress is to be adjusted for the effects of plasticity using Johnson-Ostenfeld correction formula, given below:

$$\sigma_c = \sigma_E \text{ when } \sigma_E \leq 0,5\,\sigma_0$$

$$\sigma_c = \sigma_0\left(1 - \frac{\sigma_0}{4\,\sigma_E}\right) \text{ when } \sigma_E > 0,5\,\sigma_0$$

7.3 Buckling requirements

7.3.1 This sub-Section contains requirements for the critical buckling stress for steel sandwich panels exposed to uni-axial compression.

7.3.2 The plate panel buckling requirements will be satisfied if the following is satisfied:

$$\text{Uni} - \text{axial compressive loads}: \frac{\sigma_c}{\sigma_d} \geq 1,1$$

where

σ_d = design compressive stress.

7.3.3 The design compressive stresses, σ_d, are to be taken as the global hull girder bending in accordance with *Pt 3, Ch 4 Longitudinal Strength* of the Rules for Ships. In addition, where the structural member is subject to local compressive loads, then the design stresses are to be based on these loads.

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SECTION 5 BUCKLING

Design Basis and Scantling Determination of Primary Structure

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1 **General**

2 **Primary steel support member arrangement**

3 **Primary steel support member scantling determination**

4 **Direct calculations**

5 **Buckling**

Section 1
General

1.1 Application

1.1.1 The requirements in this Chapter apply to the primary steel support members intended for use in conjunction with steel sandwich panels.

1.1.2 To determine the equivalent scantlings, the formulae given in the Rules for Ships are, in general, to be used.

Section 2
Primary steel support member arrangement

2.1 General

2.1.1 The arrangement of the primary steel support members should be such as to:

(a) ensure an aspect ratio of the panel in the range from a/b = 1,2 to 1,7 can be maintained, where a is the longest side and b the shortest side; and

(b) the largest side of the panel is less than 3,6 m.

2.1.2 The spacing of the primary steel support member is in general to be as described in *Ch 4, 2.1 General 2.1.1*. The number of primary steel support members is to be such that an adequate aspect ratio of the supported steel sandwich panel can be maintained. Additional strengthening may be required in order to achieve the aspect ratio described in *Ch 4, 2.1 General 2.1.1*.

2.2 Design details

2.2.1 Typical connection details between the steel sandwich panels and primary supporting members are given in *Ch 2, 5 Typical design details*.

2.2.2 Primary steel support members are in general to be connected to both top and bottom plating.

2.2.3 The primary support members are to be arranged and designed with sufficient stiffness to provide support to the ship's structure. In general, primary support members are to be arranged in one plane to form continuous transverse rings. Connection between primary support members forming the ring are to be provided with brackets designed in accordance with the Rules for Ships.

2.2.4 Connections between primary steel support members forming a ring system are to be designed so as to minimise stress concentrations at the junctions.

2.2.5 Primary steel support members are to have adequate lateral stability and web stiffening and the stiffening structure is to be arranged to minimise hard spots and other sources of stress concentrations.

2.2.6 Where primary steel support members are subject to concentrated loads, particularly if these loads are out of line with the member web, additional strengthening may be required.

2.2.7 Adequate transition brackets are to be fitted at the ends of effective continuous longitudinal primary steel members in the deck and bottom structures.

Section 3
Primary steel support member scantling determination

3.1 General

3.1.1 The requirements for section modulus and inertia (if applicable) of primary support members are given in the appropriate Chapters of *Pt 3 Ship Structures (General)* and *Pt 4 Ship Structures (Ship Types)* of the Rules for Ships.

3.1.2 The requirements for proportions, stiffening and construction details of primary steel supporting members are given in *Pt 3, Ch 10, 4 Construction details for primary members* of the Rules for Ships. The plate thickness requirement for deck plating forming the upper flange of underdeck girders in *Table 10.4.1 Minimum thickness of primary members* item (3) is to be applied to the combined thickness of the top and bottom plating of the steel sandwich panel.

3.1.3 In addition, where the primary steel support member contributes to the global strength of the ship, the thickness is to be not less than that required to satisfy the global strength requirements detailed in *Pt 3, Ch 4 Longitudinal Strength* of the Rules for Ships.

3.2 Geometrical properties of primary steel support member

3.2.1 In cases where the primary steel support member is not connected to both the bottom and top plating, *see Figure 4.3.1 Top plate thickness reduction (for illustration only)*, the section modulus of the primary steel support member is to be calculated by reducing the thickness of the top plating:

$$t_{1R} = \alpha t_1$$

where

t_{1R} = reduced thickness of the top plating, in mm

t_1 = minimum required thickness of the top plating, in mm, *see Ch 3, 4 Panel scantling requirements*

$\alpha = \left(14\frac{t_c}{d^2}\right)^{0,63}$

t_c, d = *see Ch 3, 4 Panel scantling requirements*.

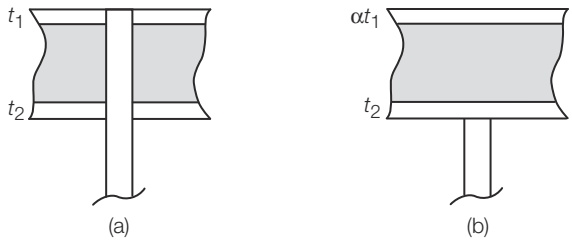

Figure 4.3.1 Top plate thickness reduction (for illustration only)

3.3 Corrosion margins

3.3.1 The requirements for primary steel support member calculated according to the Rules for Ships include a corrosion margin. No additional corrosion margin is required.

3.4 Effective breadth

3.4.1 The section moduli of the primary steel support members given by these requirements are to be determined in association with the effective attached plating as specified in *Pt 3, Ch 3, 3.2 Geometric properties of section* of the Rules for Ships.

3.5 Hull girder strength

3.5.1 For all ships, the hull girder strength requirements of *Pt 3, Ch 4 Longitudinal Strength* of the Rules for Ships are to be complied with.

3.5.2 The scantling distribution of primary steel support members contributing to the hull girder strength is to be carefully selected so as to avoid structural discontinuities resulting in abrupt variations of stress.

3.5.3 All continuous longitudinal structurally effective material is to be included in the calculation of the hull girder strength, of the hull midship section. The lever, may be measured vertically from the neutral axis to the centre of the steel sandwich panel.

3.5.4 The effective geometric properties of the midship section are to be calculated directly from the dimensions of the section using only the effective material elements which contribute to the global longitudinal strength.

3.6 Decks

3.6.1 The scantlings of primary steel support members are not to be less than those given in:

- *Pt 3, Ch 5 Fore End Structure* and *Pt 3, Ch 6 Aft End Structure* of the Rules for Ships
- *Pt 4, Ch 1 General Cargo Ships* of the Rules for Ships and the appropriate Chapter for the particular ship type.

3.7 Decks loaded by wheeled vehicles

3.7.1 The primary steel support members for decks loaded with wheeled vehicles are to be in accordance with *Pt 3, Ch 9, 3 Decks loaded by wheeled vehicles* of the Rules for Ships.

3.8 Superstructure

3.8.1 This sub-Section contains scantling requirements applicable to the internal decks of superstructure. All internal decks are to be evaluated according to *Ch 4, 3.8 Superstructure 3.8.2*.

3.8.2 The section modulus of primary steel support members is to be in accordance with the applicable rules of the Rules for Ships, *see Table 4.3.1 Applicable Rules*.

Table 4.3.1 Applicable Rules

Type of Ship	Applicable Rules
All types of ships, except:	*Pt 3, Ch 8 Superstructures, Deckhouses and Bulwarks*
Deckhouses situated on forecastles of offshore supply ships	*Pt 4, Ch 4 Offshore Support Vessels*
Ferries, Roll on-Roll-of ships and Passenger Ships	*Pt 4, Ch 2 Ferries, Roll On-Roll Off Ships and Passenger Ships*

3.9 Double bottom

3.9.1 The scantlings of primary steel support members in the double bottom are not to be less than those given in:

- *Pt 3, Ch 5 Fore End Structure* and *Pt 3, Ch 6 Aft End Structure* of the Rules for Ships.
- *Pt 4, Ch 1 General Cargo Ships* of the Rules for Ships and the appropriate Chapter for the particular ship type.

3.10 Shell envelope

3.10.1 The scantlings of primary steel support members are not to be less than those given in:

- *Pt 3, Ch 5 Fore End Structure* and *Pt 3, Ch 6 Aft End Structure* of the Rules for Ships.
- *Pt 4, Ch 1 General Cargo Ships* of the Rules for Ships and the appropriate Chapter for the particular ship type.

3.10.2 Where applicable, bottom and side shell structure below the waterline is to be evaluated against the slamming requirements in *Pt 3, Ch 5, 1.5 Strengthening of bottom forward* of the Rules for Ships.

3.10.3 Side shell structure above the waterline is not to be less than those given in *Pt 3, Ch 5, 1.6 Strengthening against bow flare slamming*, *Pt 4, Ch 2 Ferries, Roll On-Roll Off Ships and Passenger Ships* and *Pt 4, Ch 8 Container Ships* of the Rules for Ships depending on the particular ship type.

Section 4
Direct calculations

4.1 General

4.1.1 This Section gives the basic principles and requirements to be followed when carrying out direct calculations.

4.1.2 The scantlings of primary steel support members are to be examined by the applicable ShipRight Structural Design Assessment procedure for the particular ship type, *see Pt 3, Ch 16, 3 Structural design assessment* of the Rules for Ships.

4.1.3 In general the guidance provided in the applicable ShipRight procedure should be followed except with respect to the modelling of the steel sandwich panel.

4.2 Structural modelling of sandwich panel

4.2.1 In this sub-Section requirements are provided for the modelling of the sandwich panel.

4.2.2 In general, the plate element mesh is to be sufficiently fine to recover the stress at the panel boundaries. The recommended mesh sizes for sandwich structure are:

(a) for the core material two elements between the steel face plates;

(b) for the face plates a mesh size equal to the core thickness. Care is to be taken so as the aspect ratio does not to exceed 1:4.

4.2.3 Top and bottom plates of the steel sandwich panel are to be represented by shell elements and the core material by solid elements. The core material may be modelled using shell elements where it has been demonstrated that the shell element method will give equivalent result as obtained by 3-D solid element method. The nodes of the shell elements are to be placed at a distance d from each other, *see Figure 4.4.1 Modelling of sandwich by Finite Element with a combination of solid and shell elements*.

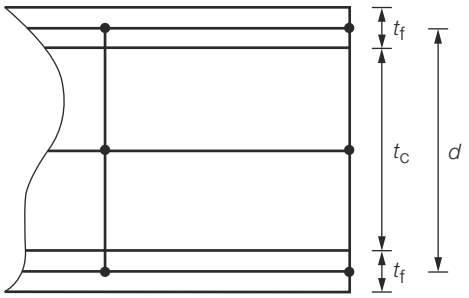

Figure 4.4.1 Modelling of sandwich by Finite Element with a combination of solid and shell elements

Section 5
Buckling

5.1 Buckling requirements

5.1.1 The elastic critical buckling stress of the web plating of the primary steel support member is to be determined from *Pt 3, Ch 4, 7.3 Elastic critical buckling stress 7.3.1* of the Rules for Ships. Additional requirements for specific ship types are also to be complied with.

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